NOVEMBER 1960
Volume 196 Part 3

JOURNAL OF THE IRON AND STEEL INSTITUTE

Established 1869
Incorporated by Royal Charter 1899

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DAVY-UNITED

FORMATION OF SERVICE DIVISION

DAVY AND UNITED ENGINEERING COMPANY LIMITED announce the formation of their new Service Division.
From 28th November, 1960, the Service Division will be located at Polmadie Works, Glasgow S.2
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NORTHERN ENGLAND—F. YAXLEY, P.O. BOX 17, STOCKTON-ON-TEES

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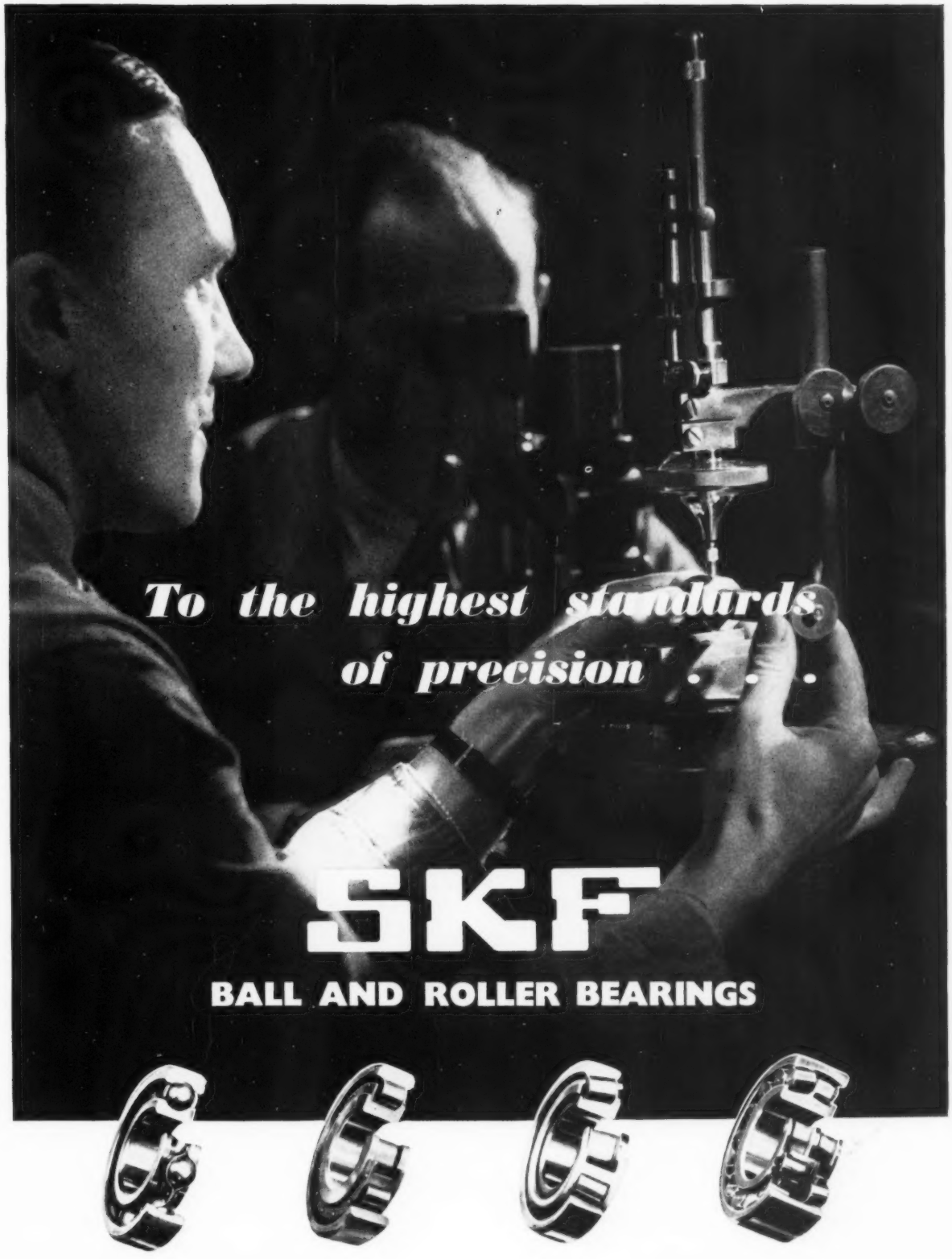

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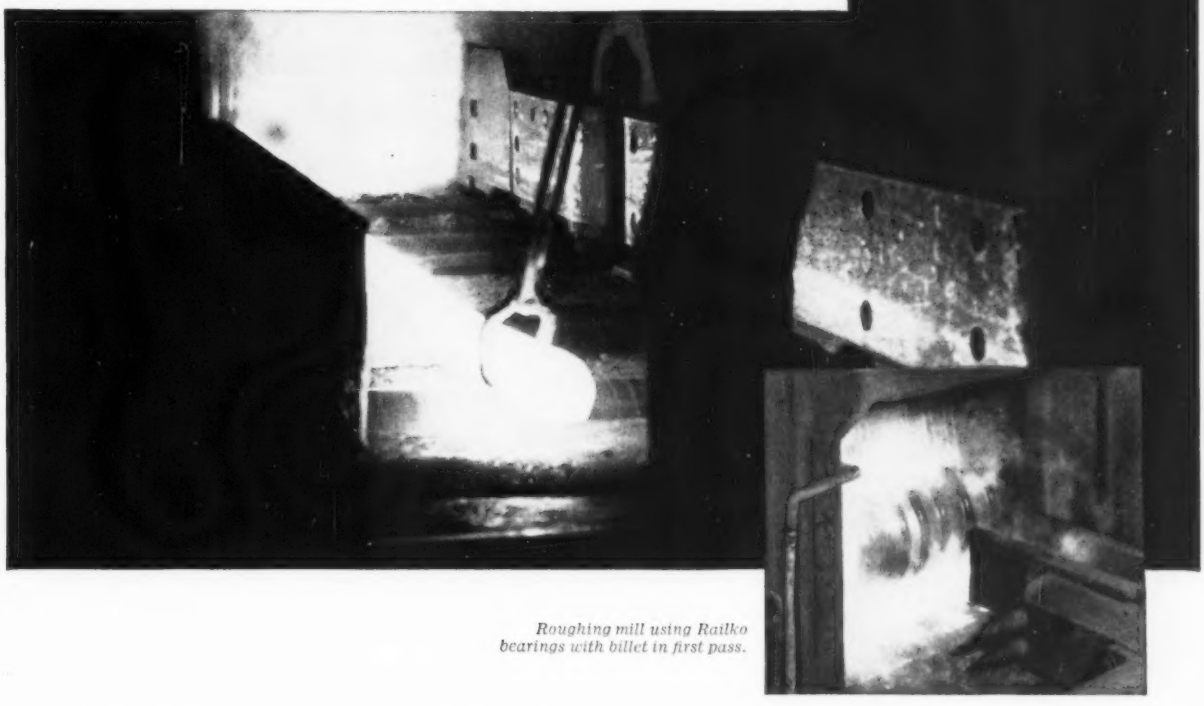

Roughing mill using Railko bearings with billet in first pass.

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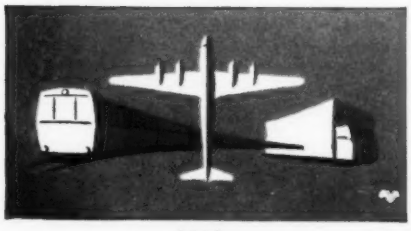

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November, 1960

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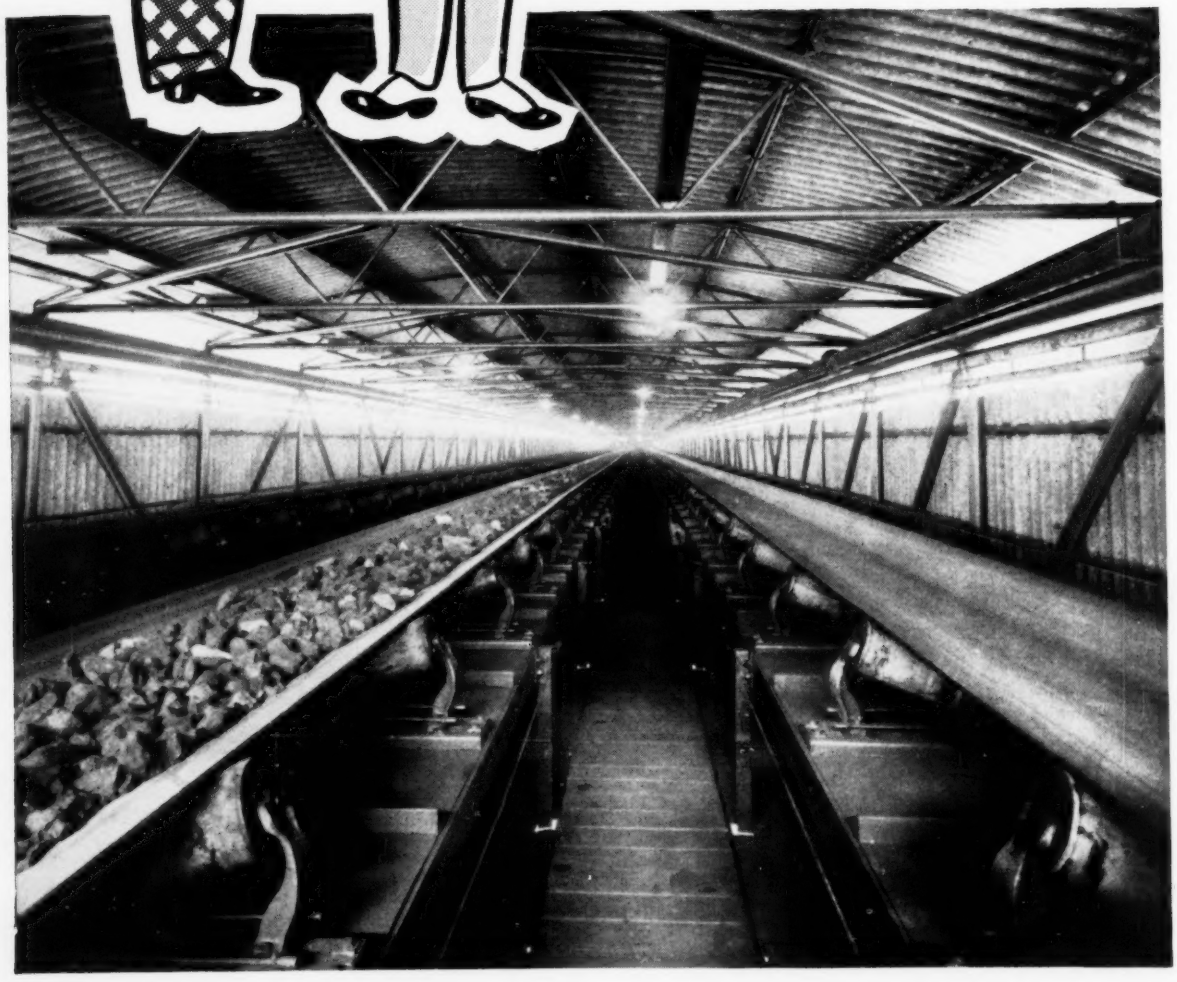

Reproduction of 16th century Dutch Print by Amman, illustrating the craft of the Pewterer. (Copyright, Radio Times–Hulton Picture Library)

Every man to his own trade –

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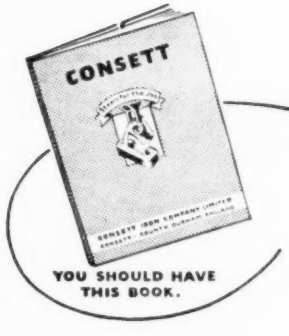
Not only mild steel for everyday use but also the special steels demanded by the Nuclear Age . . . for example we produced the special steel plates for the reactor vessels at Calder Hall, Chapelcross and Bradwell, and we are now supplying plates for the nuclear power station reactor at Latina, Italy.



An interesting booklet "Steels for the Job", just published by us, describes some of our newer products. We shall be delighted to send you a copy.

Our Technical and Research Department will also welcome enquiries from any whose problem is . . . **STEEL**

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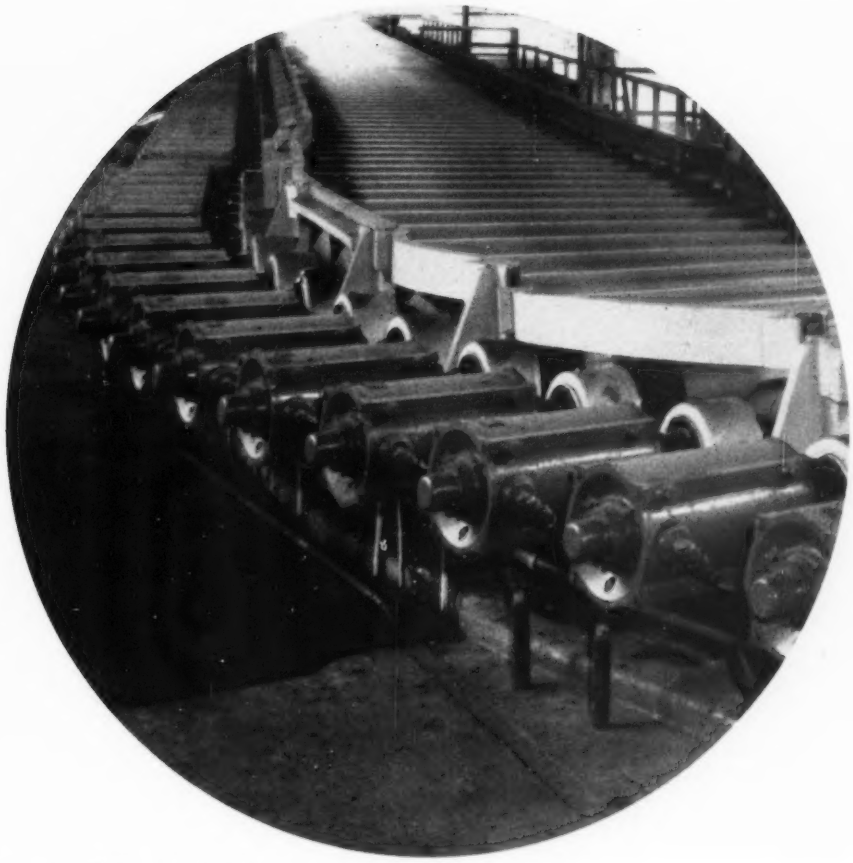
Record Blast Furnace Campaign with new Refractory
The first blast furnace in the United Kingdom to use a British super-duty firebrick for its complete stack lining has just finished its initial campaign. This is the Queen Bess furnace of the Appleby-Frodingham Steel Company and the stack was lined with M.R.2 bricks.
During its campaign the furnace produced 920,700 tons of iron involving a throughput of 2,450,000 tons of burden and 750,000 tons of coke. Throughout the entire campaign the burden consisted of 100% sinter. The tonnage handled by this furnace on such a practice is a record for the Appleby-Frodingham organisation.
AND THIS!
RECORD BROKEN
United Steel's "Queen Victoria" blast furnace at Appleby-Frodingham has beaten the record set up only a month ago by the same company's "Queen Bess" furnace—please see our release of 10th June. For the first time a British blast furnace operating with 100% sinter burden has produced over 1m. tons of iron. The campaign is continuing and the stack lining is in excellent condition. As in the "Queen Bess", the stack is lined with M.R.2 super-duty firebricks manufactured by Morgan Refractories Ltd., a subsidiary of The Morgan Crucible Company Ltd. The campaign has now lasted 112 weeks. During this period the "Queen Victoria" has been charged with 2,570,000 tons of sinter containing 36% iron, 40,000 tons of scrap and 820,000 tons of coke. 26 cwt. of slag is tapped for each ton of metal produced, so that the liquid output of the furnace so far this campaign is 2¼m. tons.
Issued by The Morgan Crucible Co. Ltd, Public Relations Dept. (Battersea 8822) on behalf of Morgan Refractories Ltd.
NE 166/A



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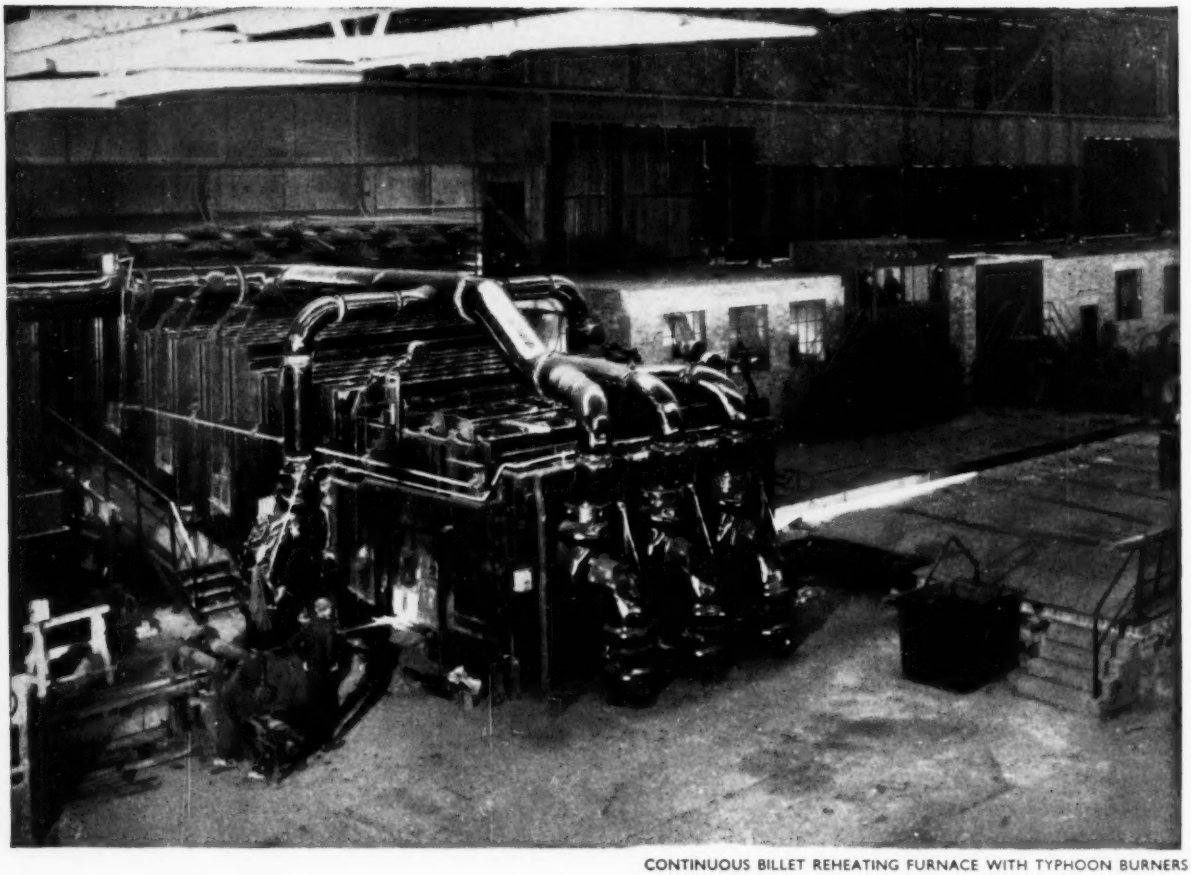

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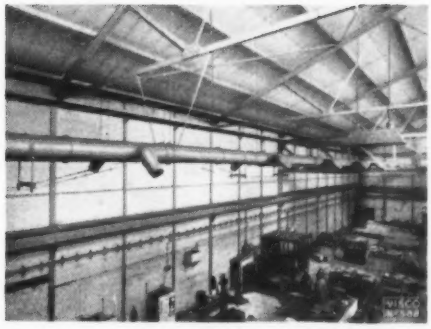
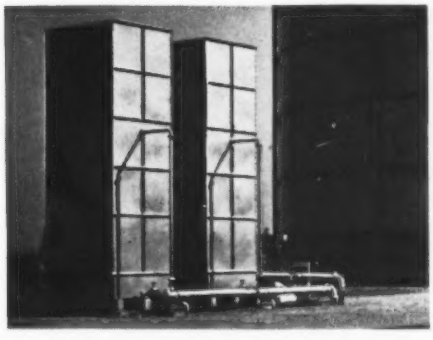


Heating and Ventilating Plant. Firth-Vickers Stainless Steel Ltd.

Visco Spray Blast Oil Coolers. At a large steelworks.



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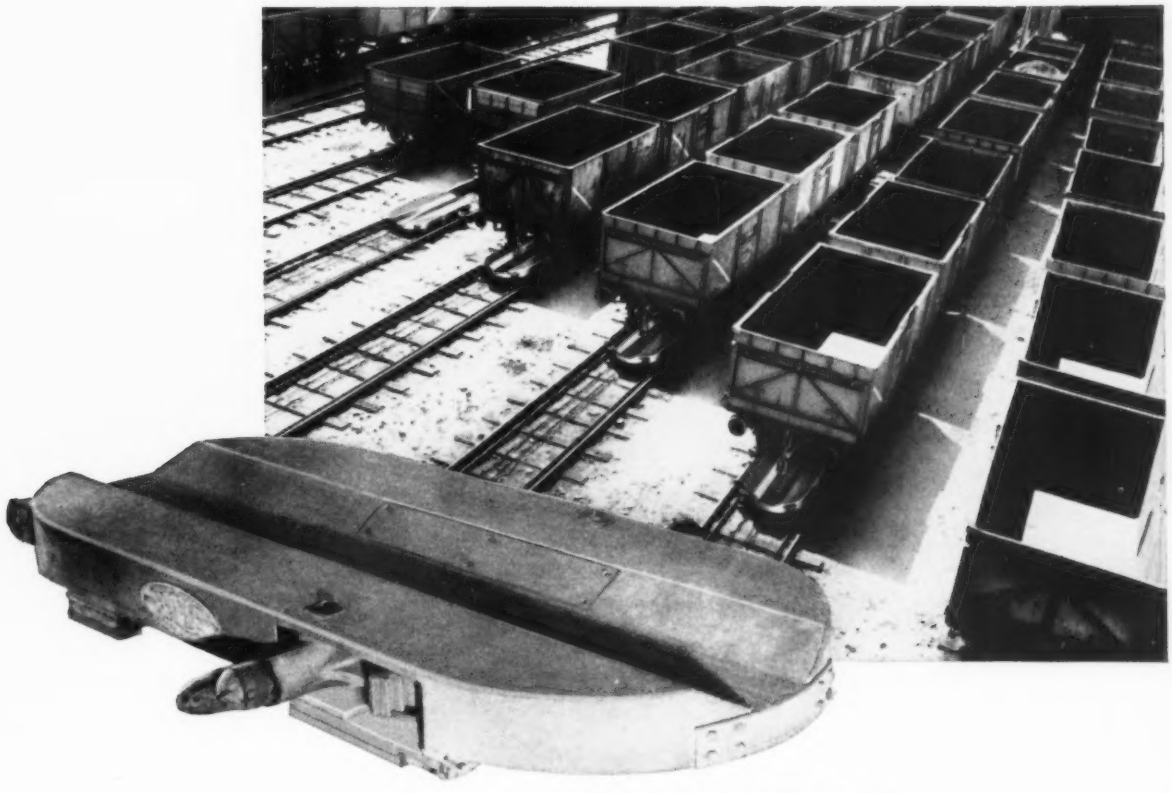

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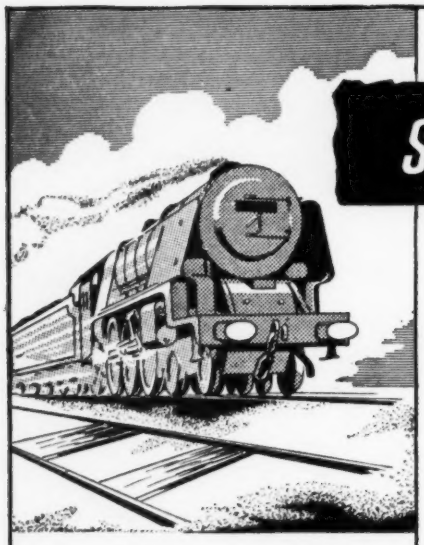

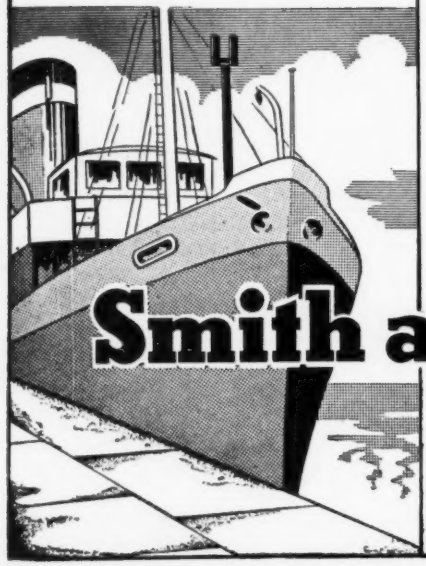

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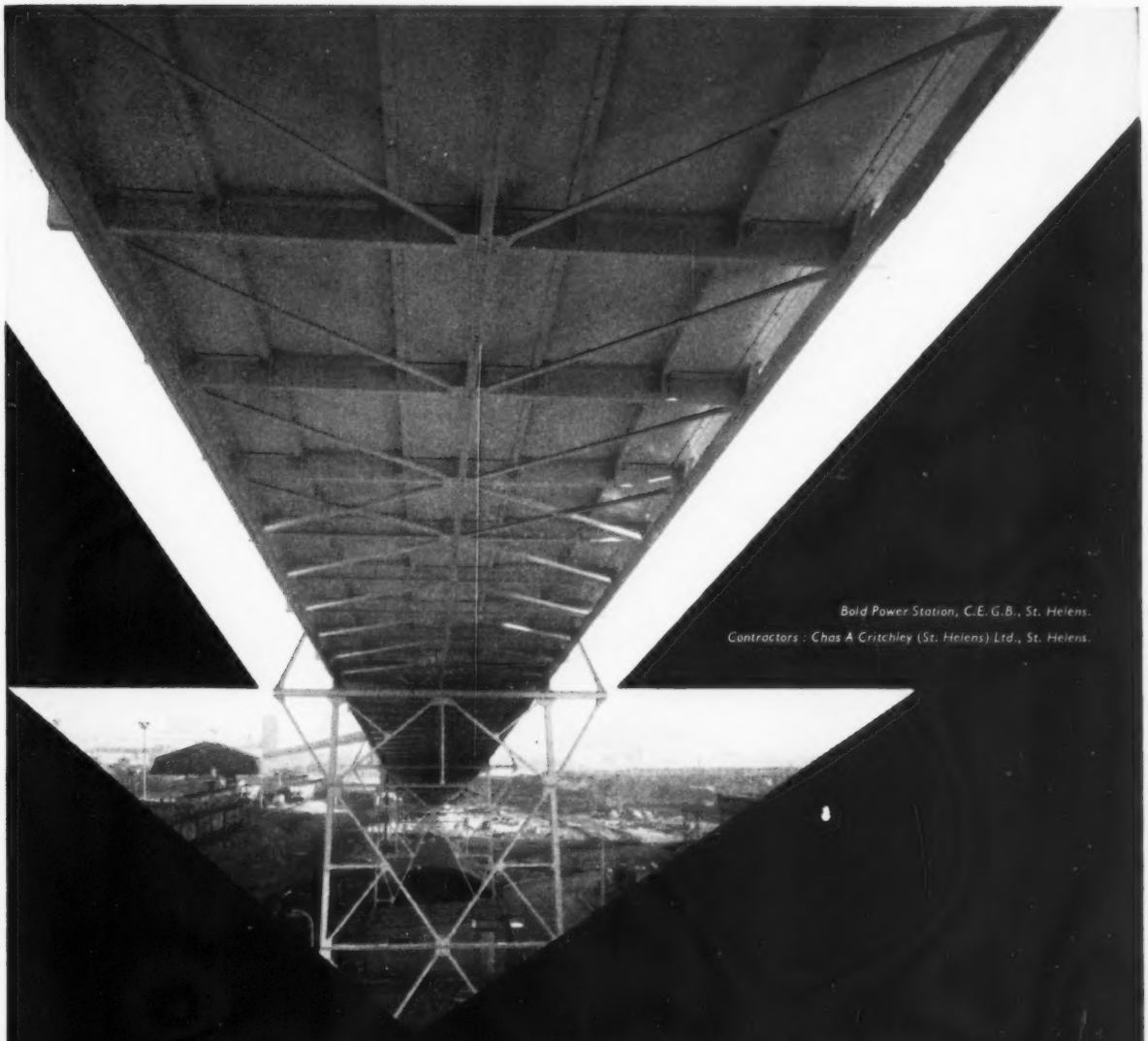

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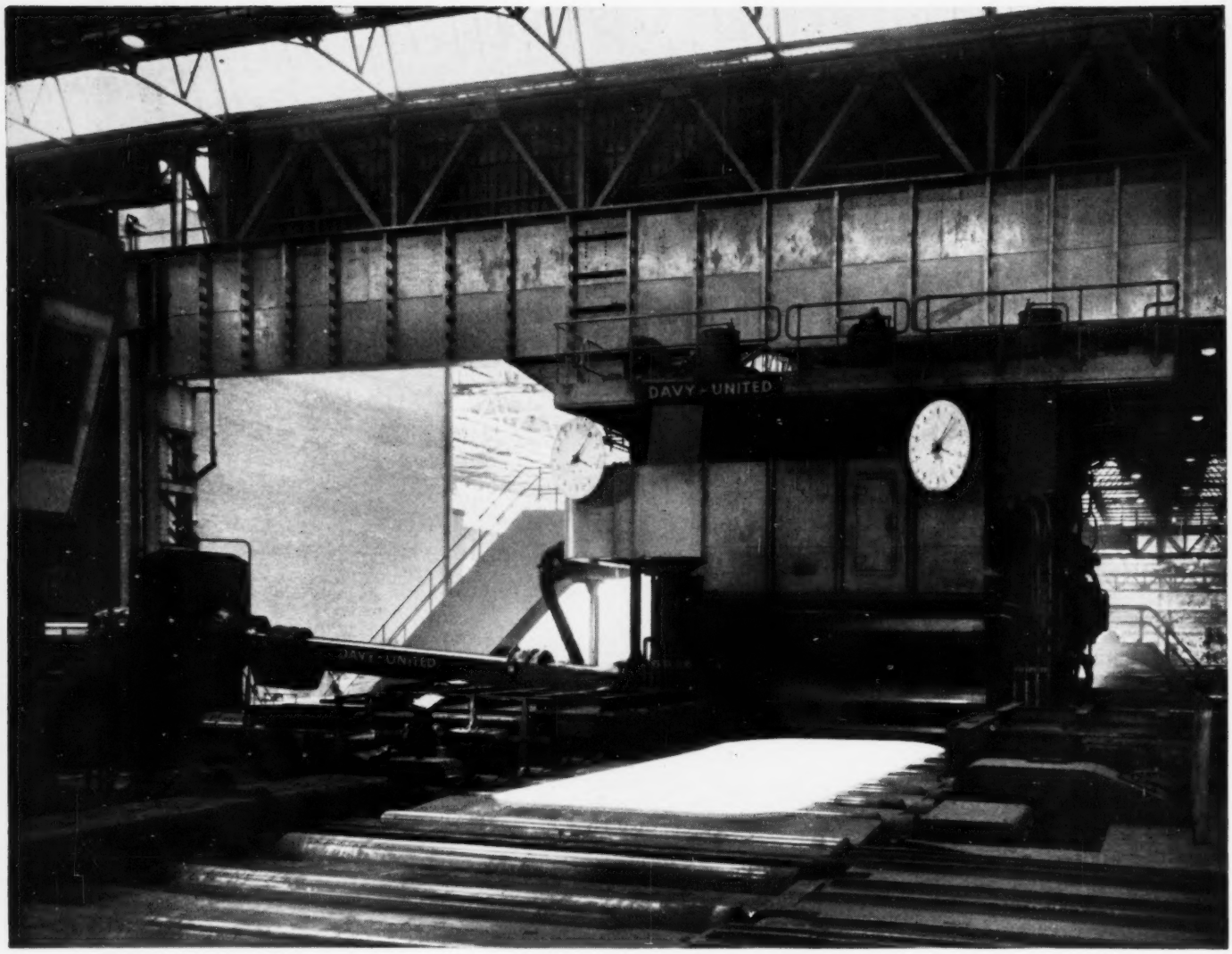

This new Hot Plate Finishing Mill is now in operation in the works of Appleby-Frodingham Steel Company. Driven by two 4,000 h.p. motors, it can roll high quality steel plate up to 12 feet wide. It is one of three new plate mill plants ordered from Davy-United under current steel industry development plans.

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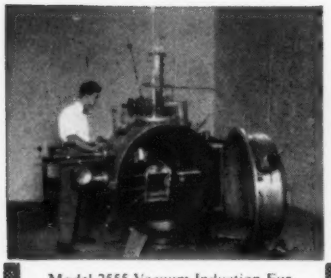
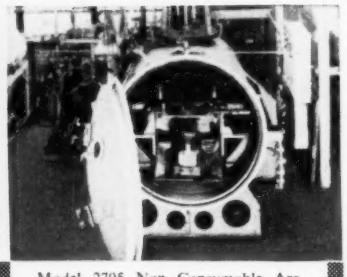


Model 2555 Vacuum Induction Furnace with melting capacity of 50 pounds of steel. Other standard furnaces have capacities of 12 to 3,000 pounds.



Model 2705 Non-Consumable Arc Skull Furnace with a capacity of 50 pounds of titanium. Other standard vacuum arc furnaces have capacities of 8 to 10,000 pounds of titanium.

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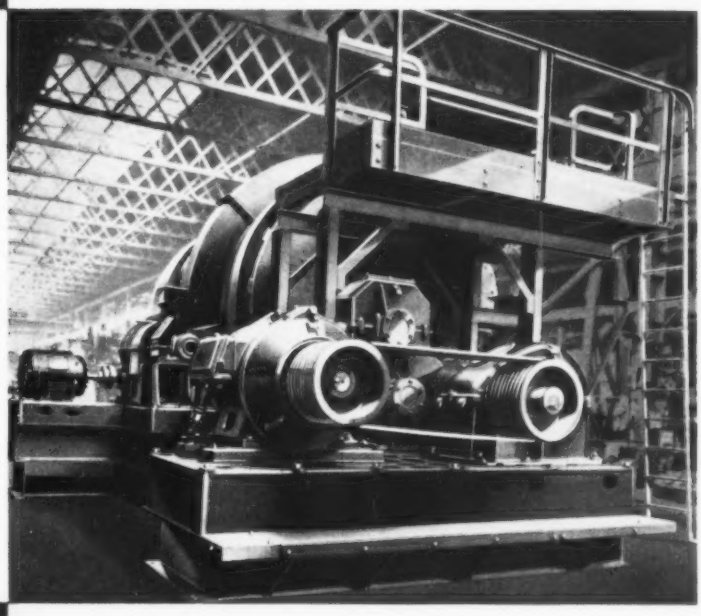

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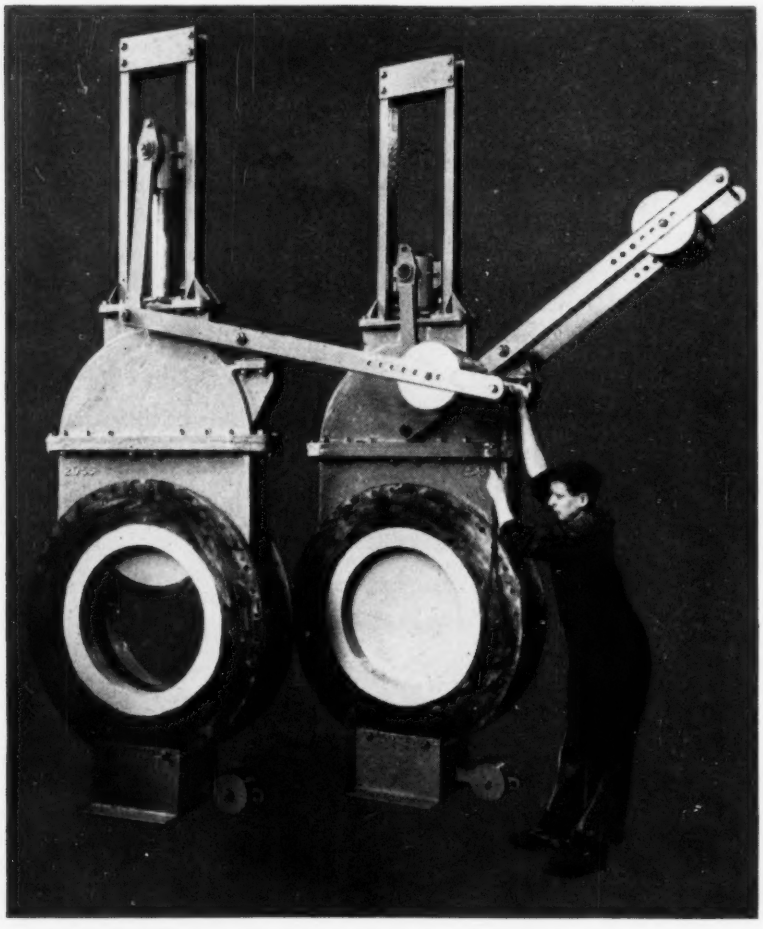

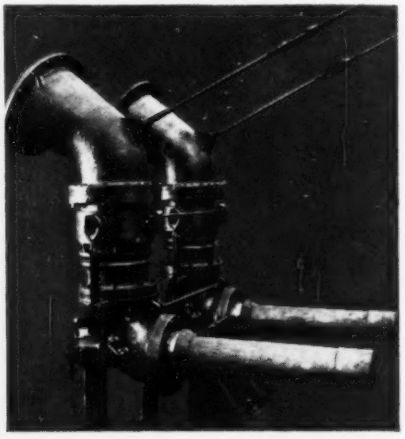

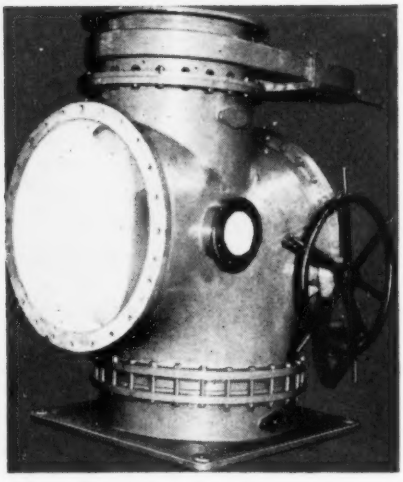

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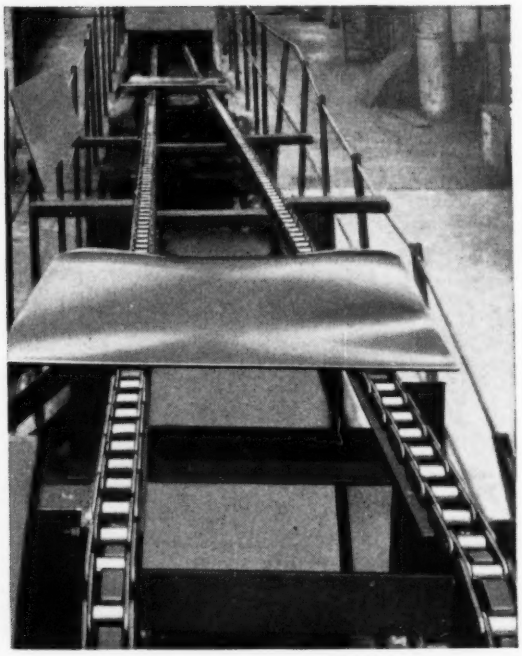
THE LOEWY REG'D. TRADE MARK **ENGINEERING COMPANY LTD.**
BOURNEMOUTH ENGLAND



for the trouble-free movement of steel– modern mills specify

RENOLD CHAINS

Exceptional strength combined with light weight and freedom from breakdown are only a few of the reasons why modern steel works install Renold chains.

Complete range is from 3,000 lb. to 300,000 lb. breaking load (up to 15,000 lb. breaking load FROM STOCK), and chains can be supplied with attachments for any duty.

RENOLD STEEL CHAINS

for conveyors and elevators

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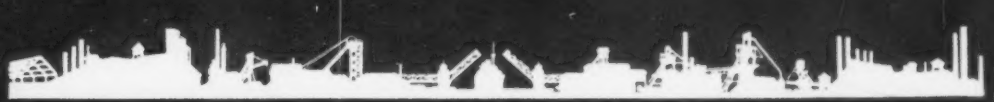
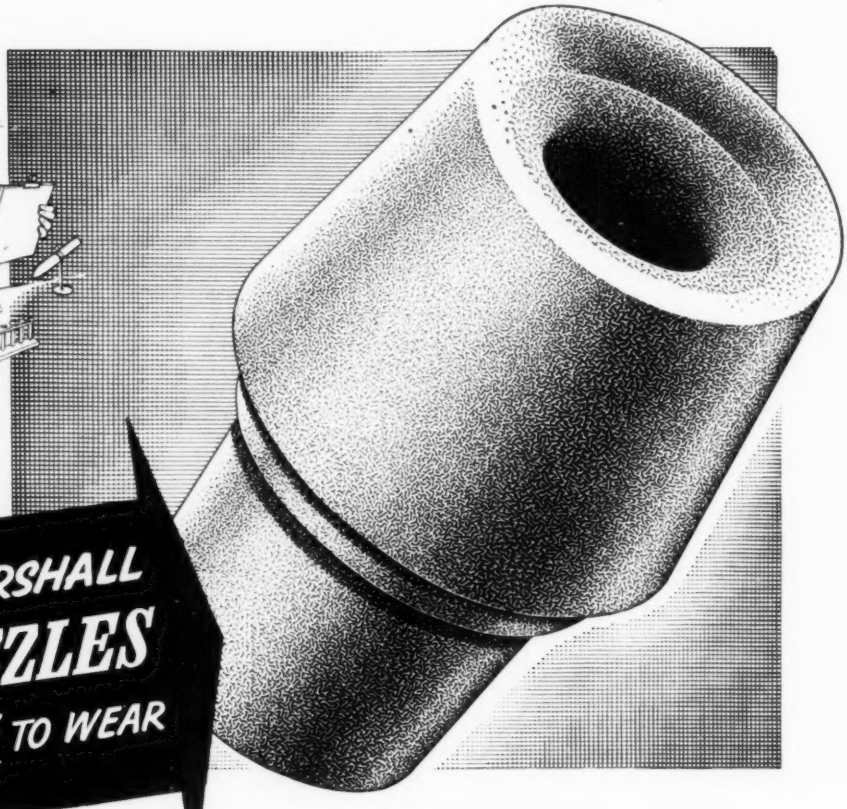


CONSTANT & CONTROLLED TEEMING *IS HERE . . .*



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To meet today's stringent specification, steelmakers are demanding better nozzles. Marshall's "CT" nozzle insert has been quickly recognised and is now accepted and widely recommended for Sulphur, Manganese and Ledloy Steels.

Let Marshall's technical advisory service help you get the right nozzle for *your* requirements.

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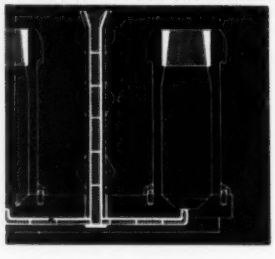

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of the specialised television in the iron and steel industry is

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Marconi's primary concern is that every installation shall be properly engineered. Where possible each installation is planned in detail on site, ensuring that the equipment will be used correctly and will thus give absolutely reliable service. Proper system planning is vital to satisfactory installation and is provided free of charge.

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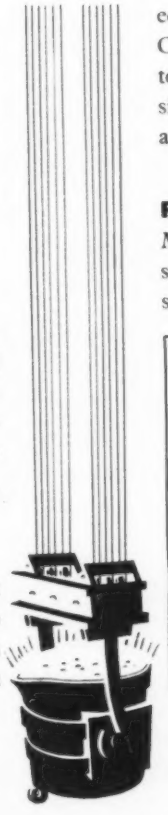

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in providing an engineering service to the Metal Industries

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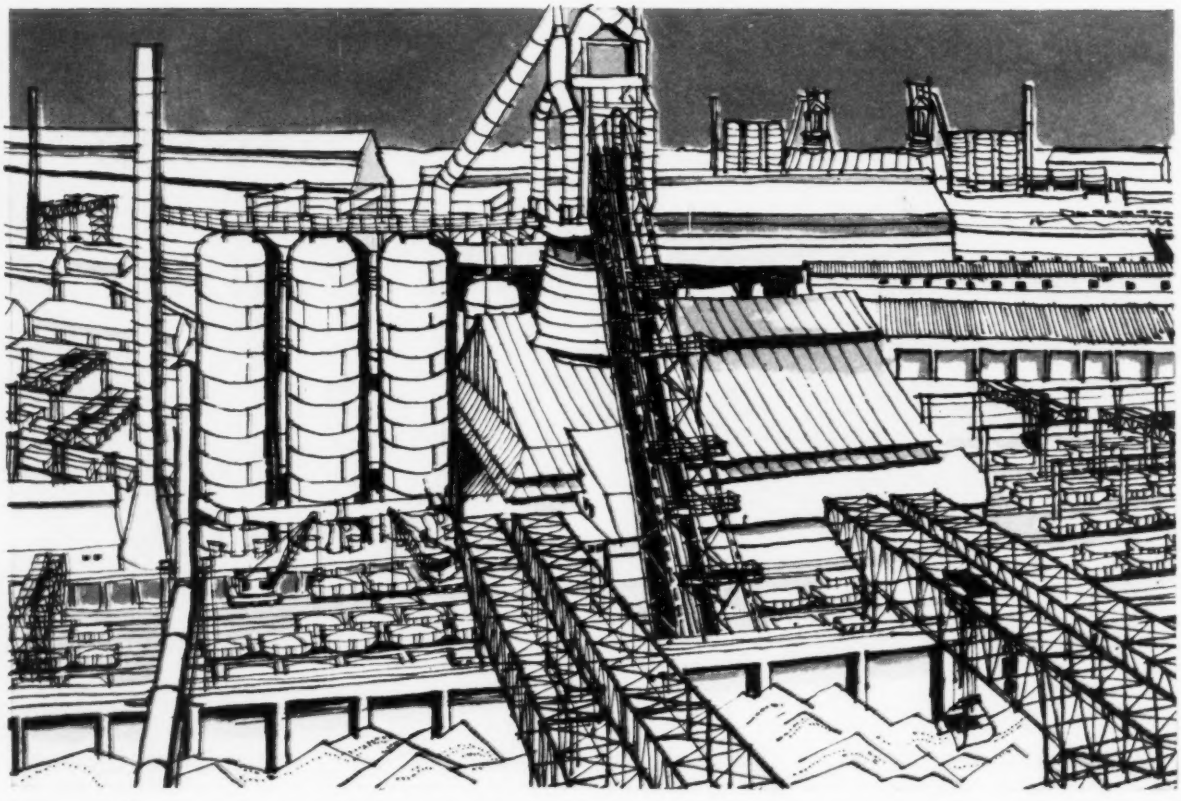

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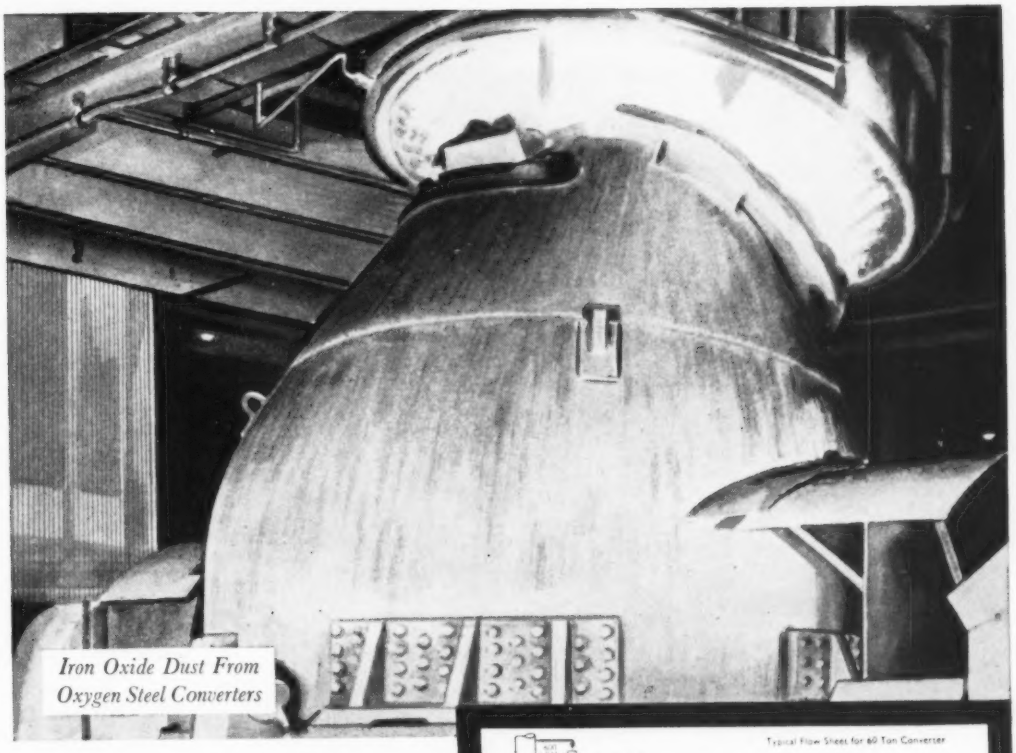
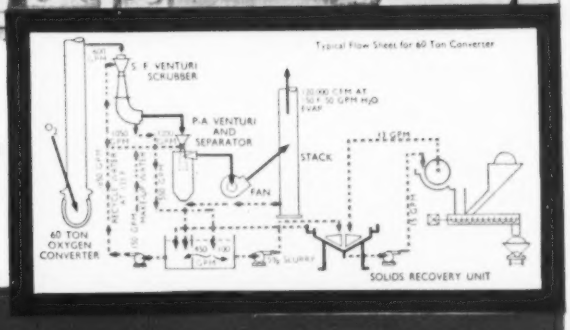


Iron Oxide Dust From Oxygen Steel Converters



remove it wet... recover it dry

The recent installation of Chemico Venturi Gas Scrubbers at a major steel plant in Canada marks the sixth time Venturi Gas Scrubbers have been used to prevent an extremely undesirable source of air pollution —Iron Oxide Dust. Chemico Venturi Scrubbers maintain leadership in the world's steel industries because they offer wet scrubbing which allows non-explosive collection, efficiencies above 99% and extremely low maintenance. In addition no critical controls are required to maintain efficiency and the handling of dust is simplified by recovery in a dry form. Chemico Gas Scrubbers are ideally suited for Open Hearth Furnaces, Cupolas, Scarfing operations, Sintering operations, and Electric Furnaces. For further information and a copy of a brochure giving full particulars, contact the Chemico Gas Scrubber Division:

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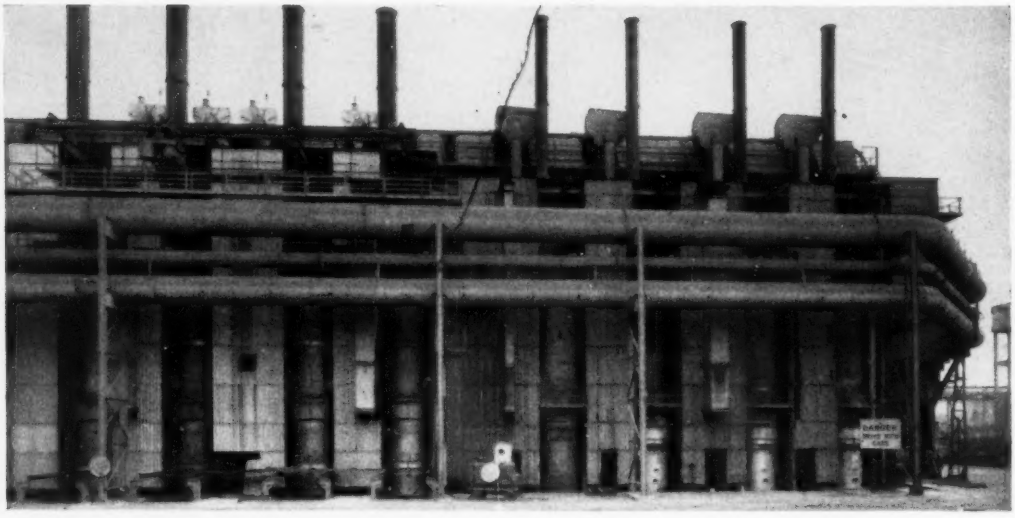
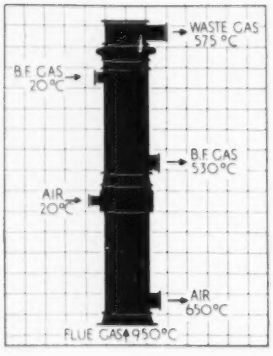
A SUBSIDIARY OF CHEMICAL CONSTRUCTION CORPORATION, NEW YORK, U.S.A.

M.E./SCHACK RECUPERATORS FOR SOAKING PITS





The eight sets of M.E./Schack convection flue tube recuperators shown in the above photograph are mounted on eight one way fired soaking pits at the Appleby-Frodingham Steel Co., Scunthorpe. The recuperators are mounted in "tower" formation, the gas recuperator being directly over the air recuperator as shown in the sketch on the left. The latest four sets are designed for heating 170,000 c.f.h. of combustion air to 650°C, and 230,000 c.f.h. of blast furnace gas to 530°C.

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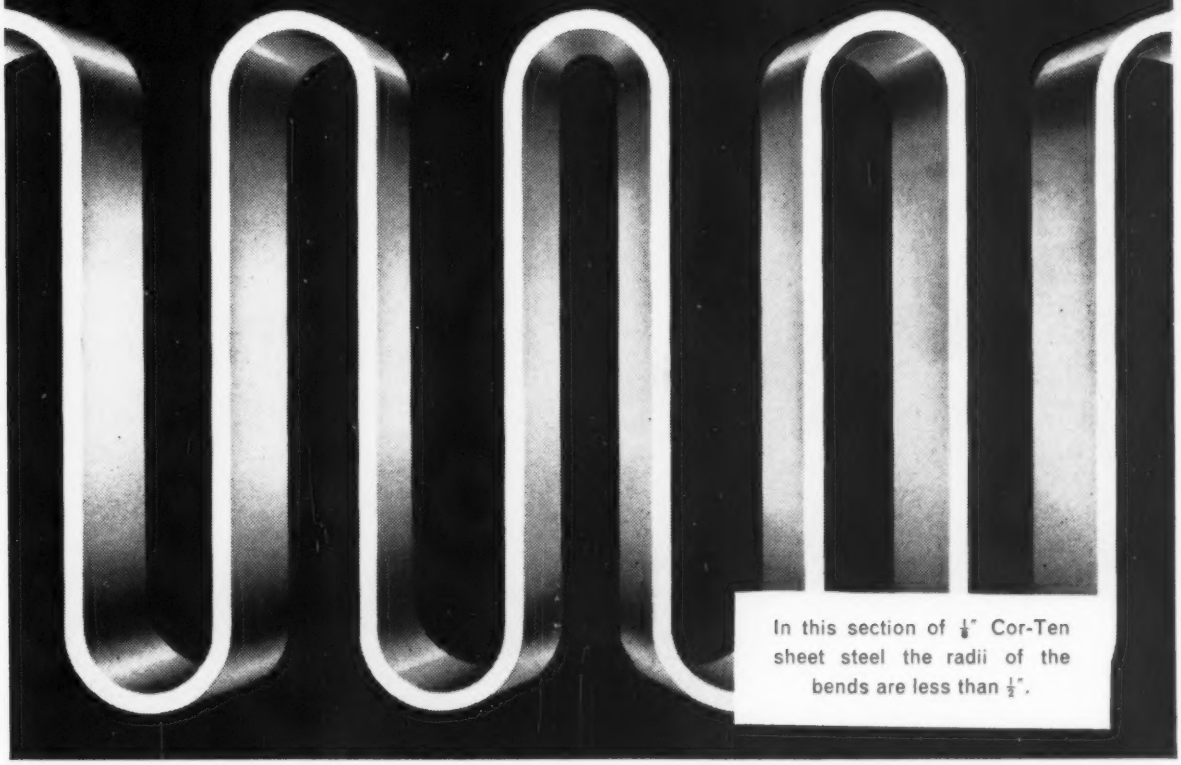
UNION CARBIDE CO-OPERATION WITH THE STEEL COMPANY OF WALES LIMITED MADE THIS POSSIBLE



In this section of $\frac{1}{8}$" Cor-Ten sheet steel the radii of the bends are less than $\frac{1}{2}$".

The Alloys Development Department of Union Carbide Limited, London, in their continuous search for new ways to make better steel, always work in close co-operation with the steelmakers themselves. They gratefully acknowledge the help of The Steel Company of Wales Limited who made it possible to run tests on the latest Union Carbide alloy additive—SILCHROMSOL. SILCHROMSOL, a new silicon chrome alloy additive, is now used in the production of SCW COR-TEN* high strength low alloy steel.

Photomicrographs show that the intermetallic compounds present when the steel is made with SILCHROMSOL are of a spherical shape instead of the "stringer" type which are associated with a lack of ductility. Tests indicate that SILCHROMSOL gives this type of steel vastly improved ductility. The new development has been well received and The Steel Company of Wales Limited have great confidence in the improvements which will result.

* SCW COR-TEN *steel is made in this country under licence from the United States Steel Corporation.*

CO-OPERATING WITH INDUSTRY

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UNION CARBIDE LIMITED · ALLOYS DIVISION · 8 GRAFTON STREET · LONDON, W.1 · MAYFAIR 8100

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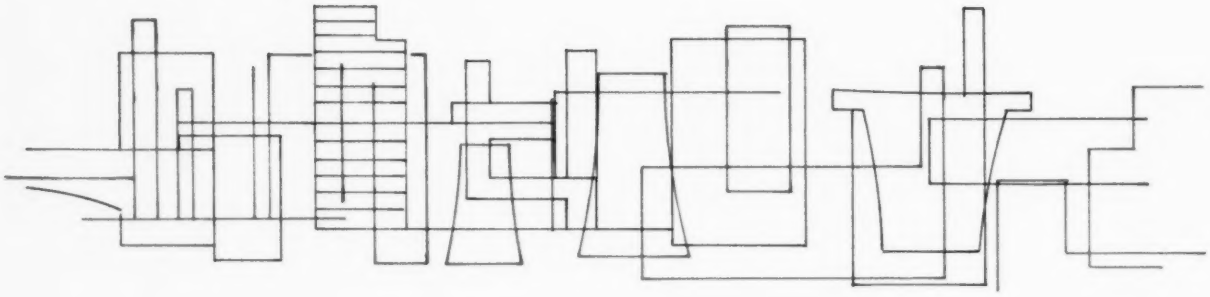

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Photo by courtesy of Messrs. Thos. Firth & John Brown Ltd.

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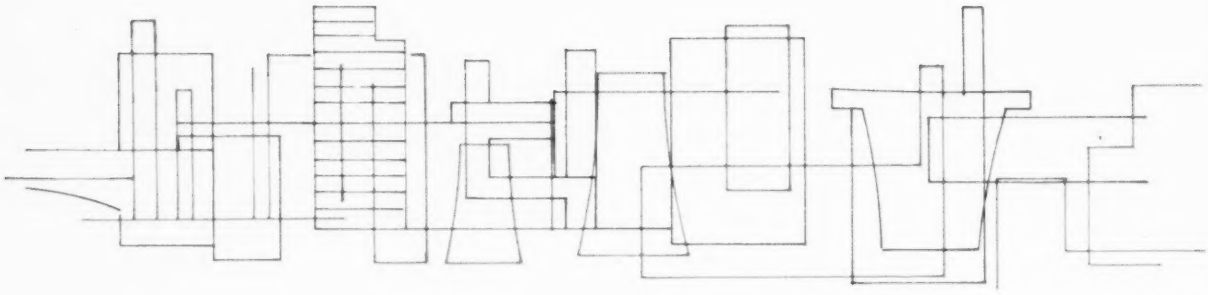

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100 TON ALL BASIC
OIL FIRED OPEN HEARTH FURNACE

Installed at The Albion Steel Works of The Briton Ferry Steel Co. Ltd.

This O.H. Furnace is providing consistently high outputs on cold charge material with excellent overall economy.

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Sole representatives in Britain for **MAERZ** *open hearth furnaces*

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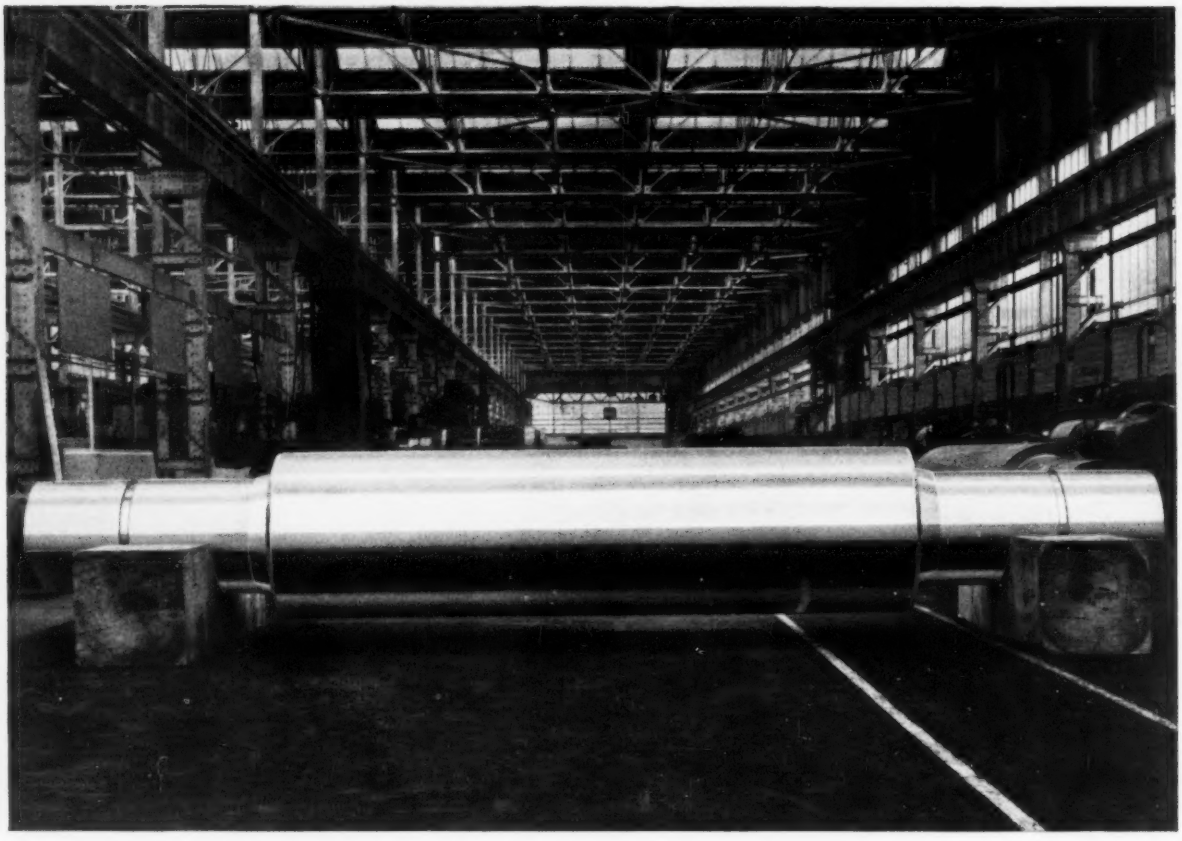

This heavyweight turned the scales at 28 tons, 10¼ cwts. It is a Duplex Manganite Alloy Indefinite Chill Work Roll, 39″ × 150″ × 266″, for a 4 High Plate Mill. From this, to the smallest work roll, you can rely on us for accuracy and quality.

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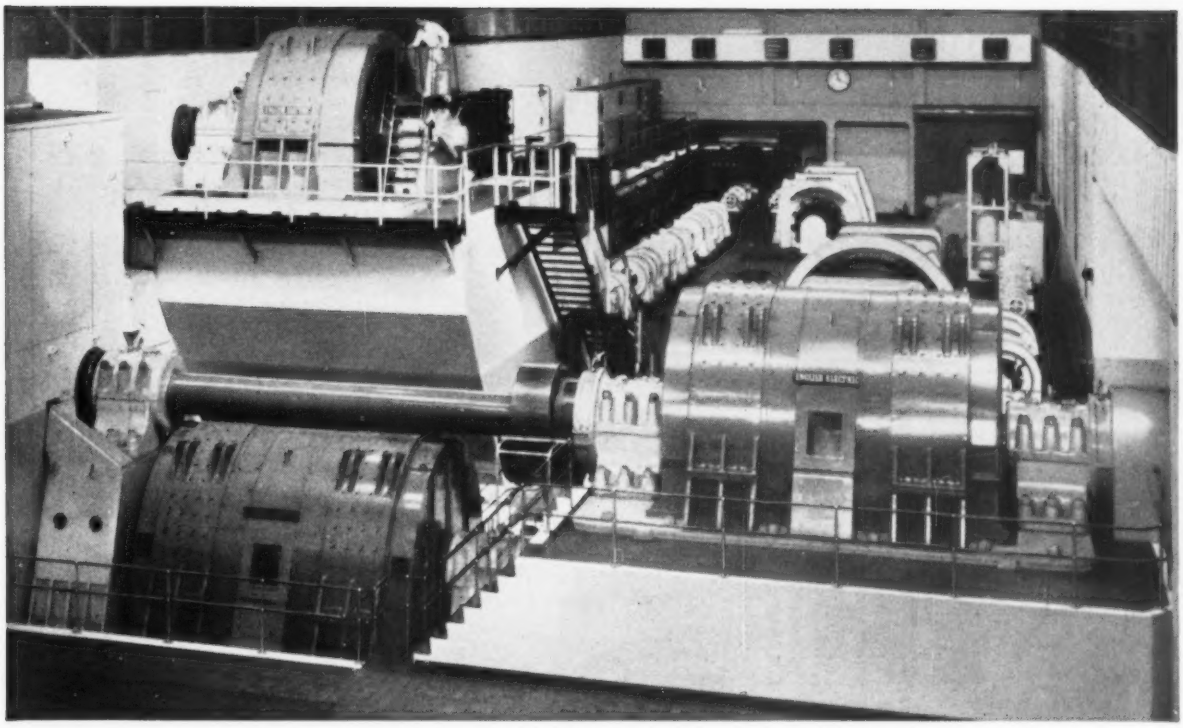

Motor room of the universal slabbing mill, The Steel Company of Wales.

FIRST AGAIN

Still using the original 'ENGLISH ELECTRIC' twin-drive motors installed over ten years ago, Britain's first twin-drive, hot reversing, 45-inch slabbing mill at the Abbey Works of The Steel Company of Wales was transformed into Britain's first universal slabbing mill.

A new mill stand having additional edger rolls driven by a 4,000 h.p., r.m.s. 'ENGLISH ELECTRIC' motor was installed. This brought the total output of the main drive motors to 13,000 h.p., r.m.s. with a maximum cut-out of three times full load torque.

The change-over to 'universal' was completed with only twelve days' loss of production.

'ENGLISH ELECTRIC'

steelworks equipment

THE ENGLISH ELECTRIC COMPANY LIMITED, ENGLISH ELECTRIC HOUSE, STRAND, LONDON, W.C.2

Metal Industries Division, Stafford

WORKS: STAFFORD · PRESTON · RUGBY · BRADFORD · LIVERPOOL · ACCRINGTON

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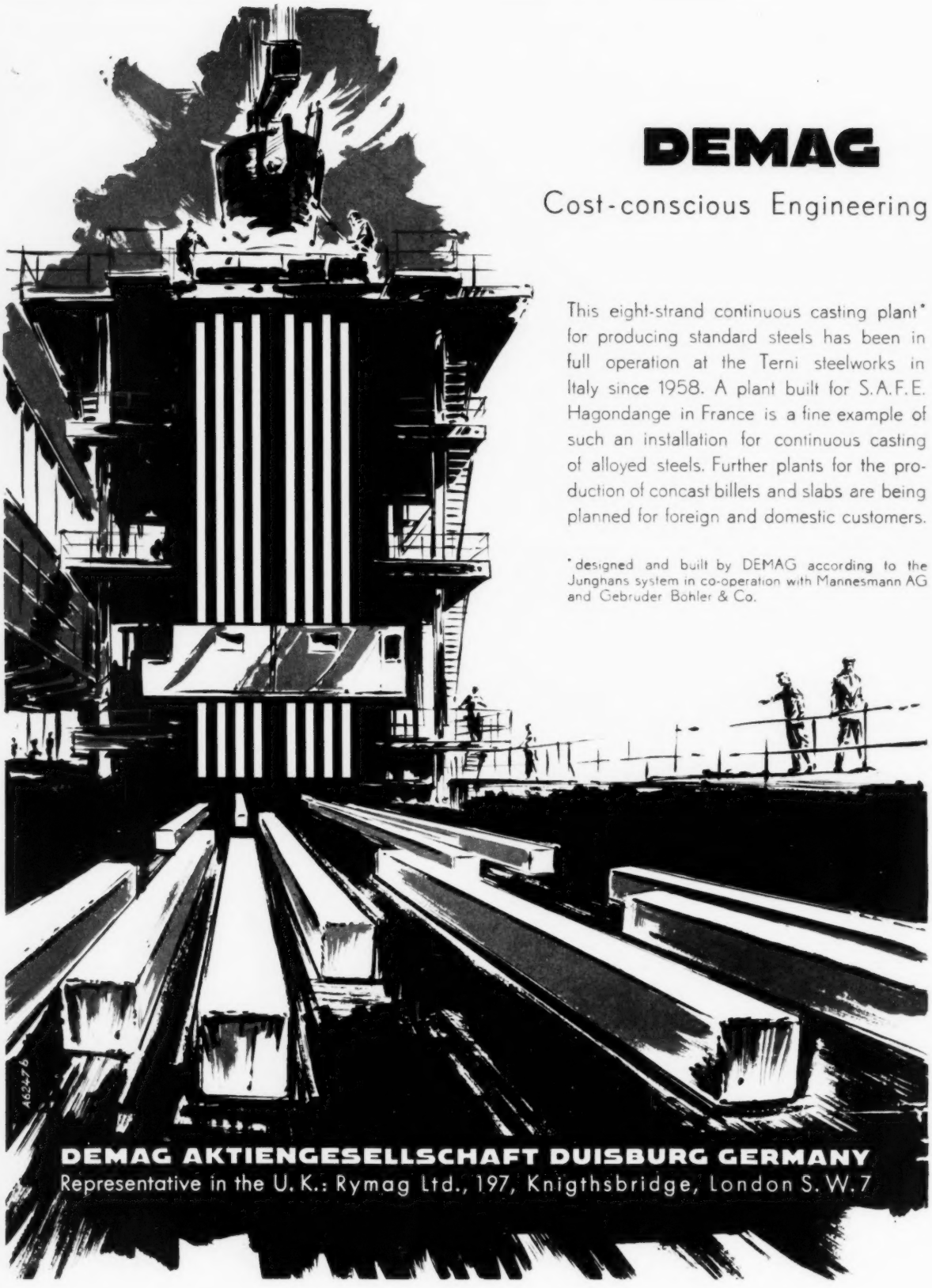

DEMAG

Cost-conscious Engineering

This eight-strand continuous casting plant* for producing standard steels has been in full operation at the Terni steelworks in Italy since 1958. A plant built for S.A.F.E. Hagondange in France is a fine example of such an installation for continuous casting of alloyed steels. Further plants for the production of concast billets and slabs are being planned for foreign and domestic customers.

*designed and built by DEMAG according to the Junghans system in co-operation with Mannesmann AG and Gebruder Bohler & Co.

DEMAG AKTIENGESELLSCHAFT DUISBURG GERMANY

Representative in the U.K.: Rymag Ltd., 197, Knigthsbridge, London S.W.7

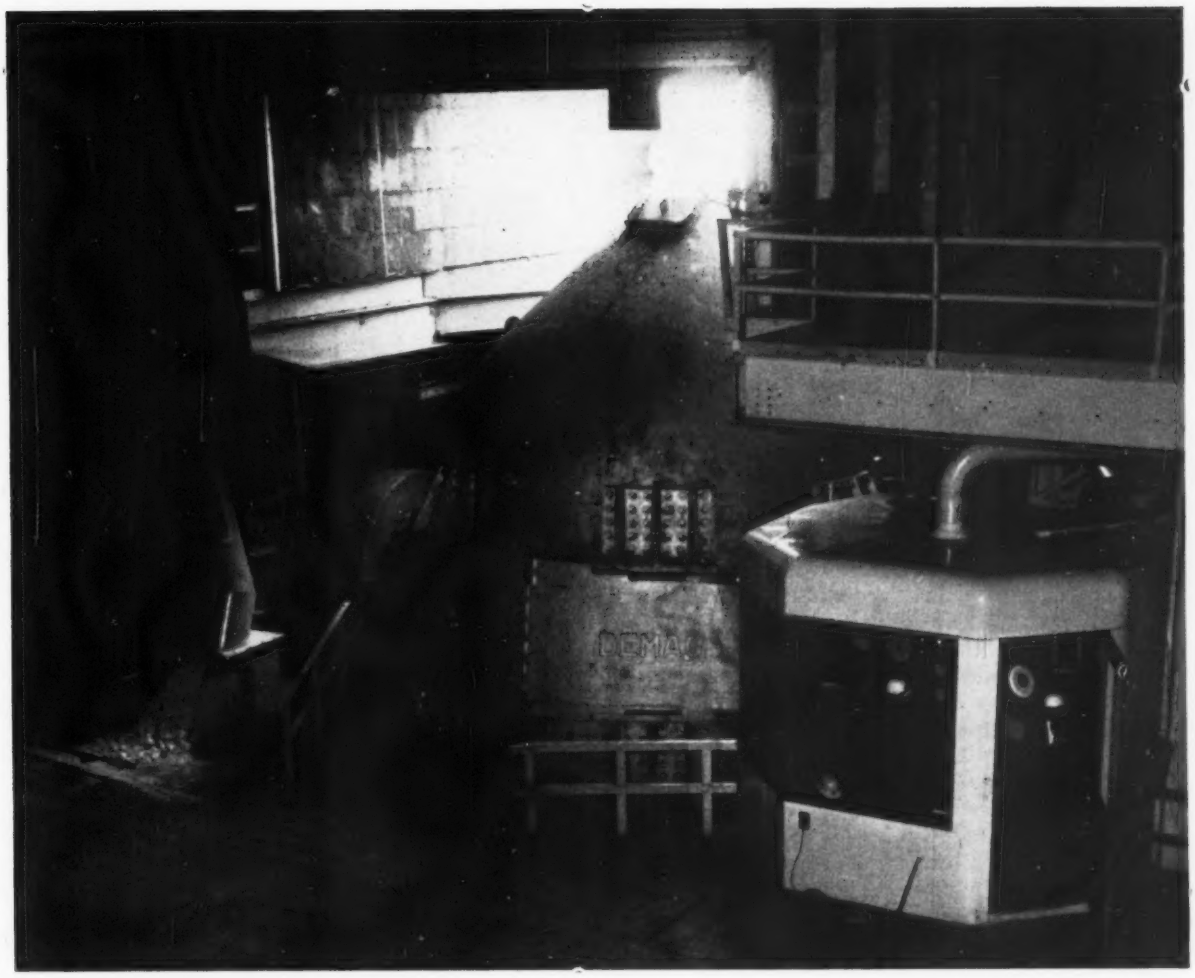

Photo courtesy Steel Co. of Wales

INSTRUMENTS AND CONTROLS FOR THE

BASIC BESSEMER PLANT

AT THE STEEL COMPANY OF WALES LTD.

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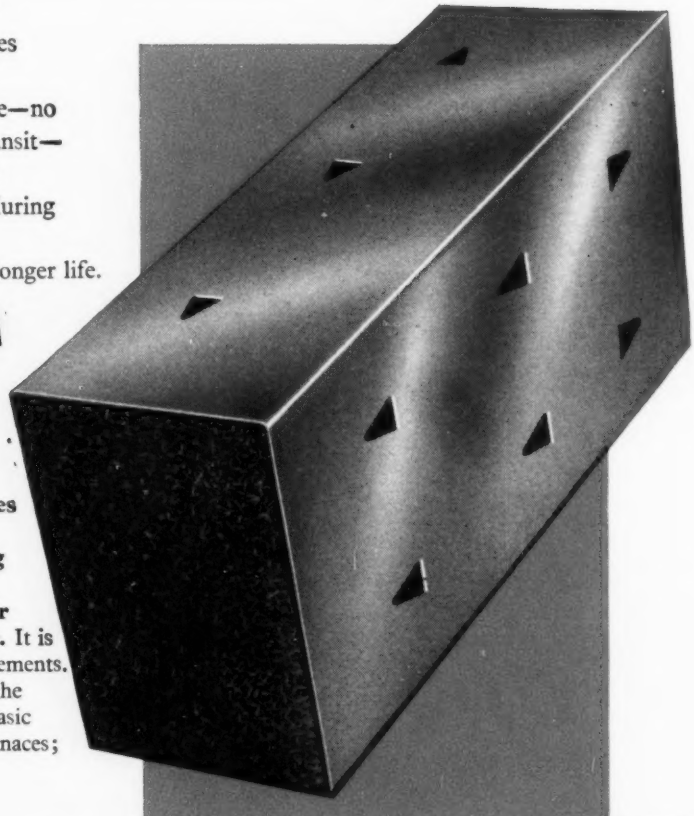
G.R. FERROCLAD (Metal Cased) BRICKS

-meet the demands of MODERN STEEL MAKING PROCESSES

Ferroclad bricks are steel-clad on four sides, and have the following advantages over the traditional fired bricks:—

Absolute accuracy of shape and size—no loose plates—no damage during transit—easy to install—no jointing cement required—elimination of spalling during temperature changes—iron-oxide bursting reduced to a minimum—longer life.



COVERED BY BRITISH PATENT Nos. 546, 220

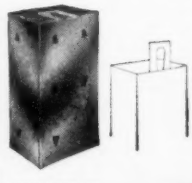
For over 10 years General Refractories Ltd. have manufactured steel-clad basic bricks under licence by the Heuer processes. **One of the principal features of Ferroclad is that the graded refractory material and metal casing form an integral unit by means of controlled hydraulic pressure—no air infiltration—the case fits like a glove.** It is made in four main qualities to suit requirements. Ferroclad bricks are extensively used in the roof, front and back walls, and ends of basic open hearth furnaces; in basic electric furnaces; and in copper reverberatory furnaces.

FERROCLAD 'EE' BRICKS

Divided internally by two plates placed lengthwise. This system reduces flaking and spalling to a minimum and can be applied to all Ferroclad shapes and sizes.

COVERED BY **BRITISH PATENT Nos. 546, 220., 778, 047., and 778, 048**

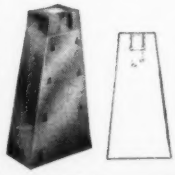
TABHANGER SUSPENSION



Bricks supplied with a special stainless steel tab co-moulded with the brick, embedded into the surface of the top face. By the use of a special tool the tab may be bent out at right angles to the top face to form a hanger.

COVERED BY **BRITISH PATENT Nos. 546, 220 and 749, 491**

FERROCLIP SUSPENSION



This method allows the brick to be suspended from the end. The Ferroclip hanger slot may be moulded into any roof or wall shape.

COVERED BY **BRITISH PATENT Nos. 546, 220 and 600, 630**

During recent years the demand for Ferroclad has increased so tremendously, that General Refractories Ltd. have granted a sub-licence to Messrs. Pickford Holland & Co. Ltd. to manufacture similar products within the scope of the British Patents mentioned above.

The basic process of metal-cased brick manufacture is covered by British Patent No. 546,220 and other additions, including the "Ferroclip," the "Tabhanger" and the "EE", are covered by British Patent Nos. 546,220, 600,630, 749,491, 778,047 and 778,048.

full technical information on request

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Enquire at your nearest I.C.I. sales office for further details.

British licensee of the Tigerschiold method (Brit. Pat. No. 778,039) is Hinckley's Ltd., Sheffield 7. The CO_2/silicate process is protected by Brit. Pat. No. 654,817.

I.C.I. products for the CO_2/silicate process

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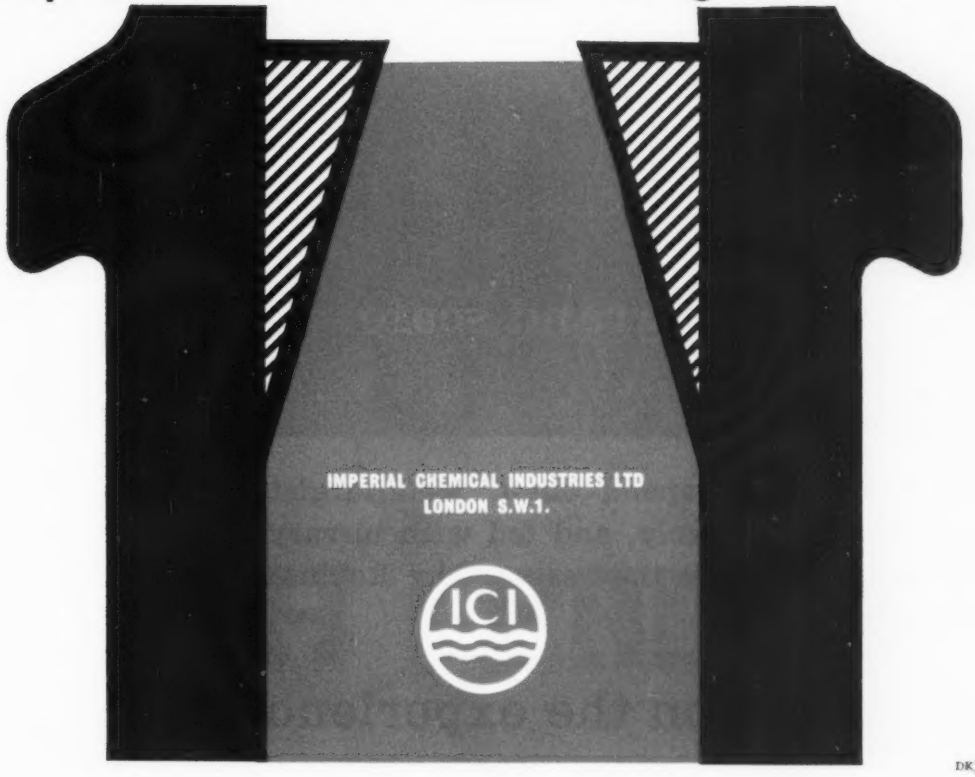
'Drikold' and the 'Drikold' Liquefier — for the small user. I.C.I. Liquid Carbon Dioxide in Bulk and the 5-ton capacity storage tank — for the large user.

SODIUM SILICATE

Grades C.112 and C.125 — supplied in 10-gallon or 45-gallon drums, and in road or rail tank vehicles.

New Hot-top method reduces steel-making costs!



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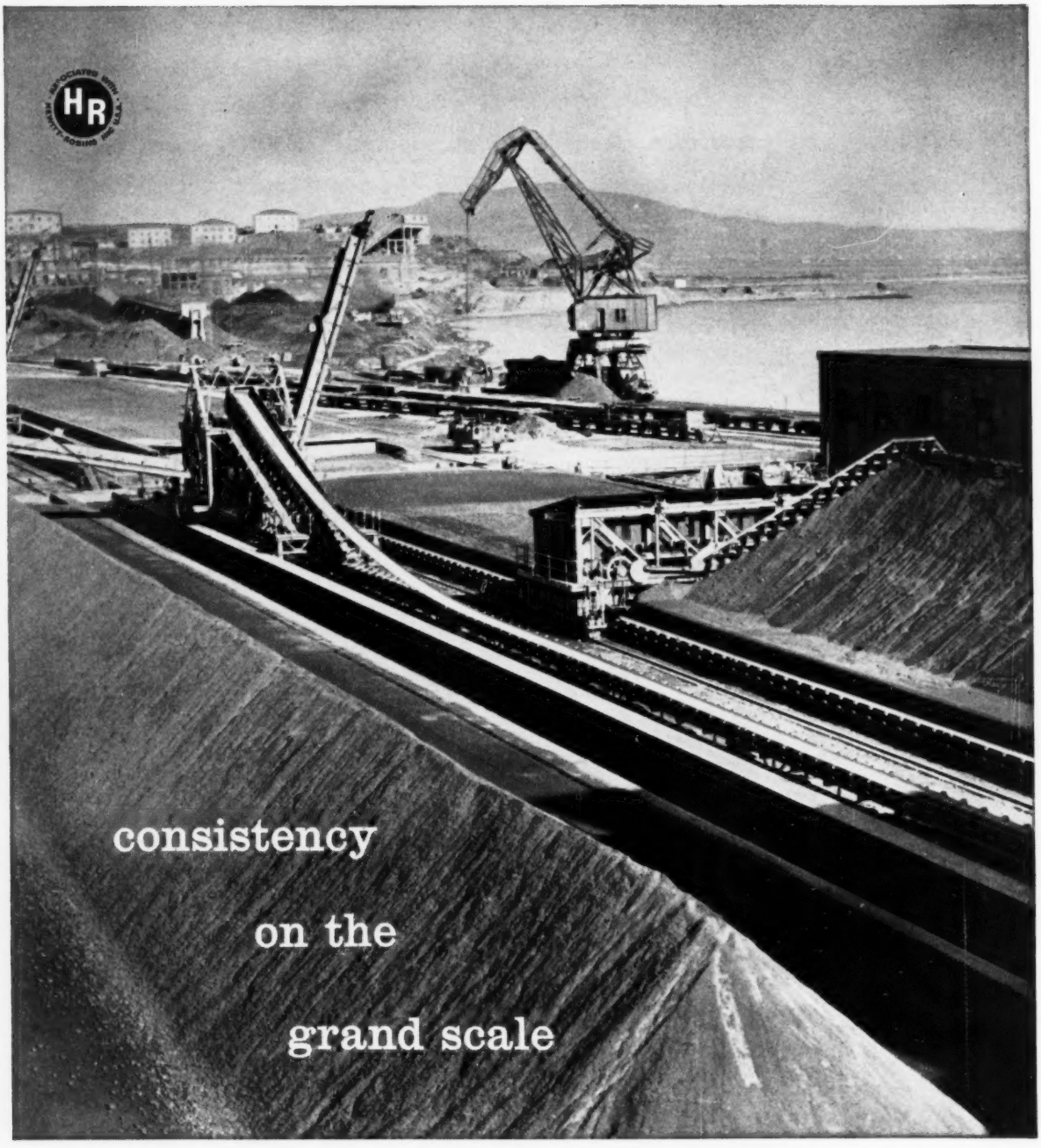

Blast furnaces depend on it. Metallurgists count on it... Ores must be blended precisely, and fed with unvarying consistency to the blast furnace... That is the reason why Robins-Messiter blending plant was installed in Italy.

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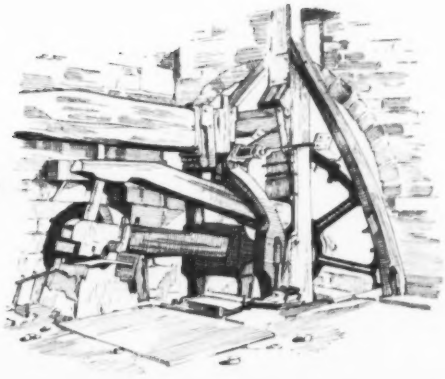
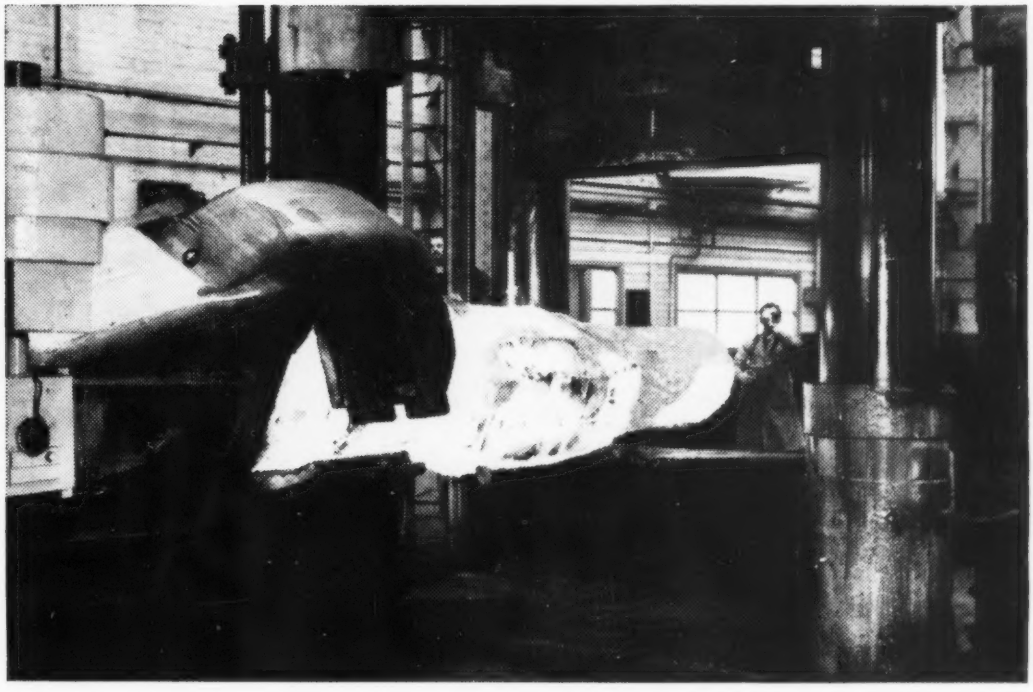
Steel in Both the Sixties





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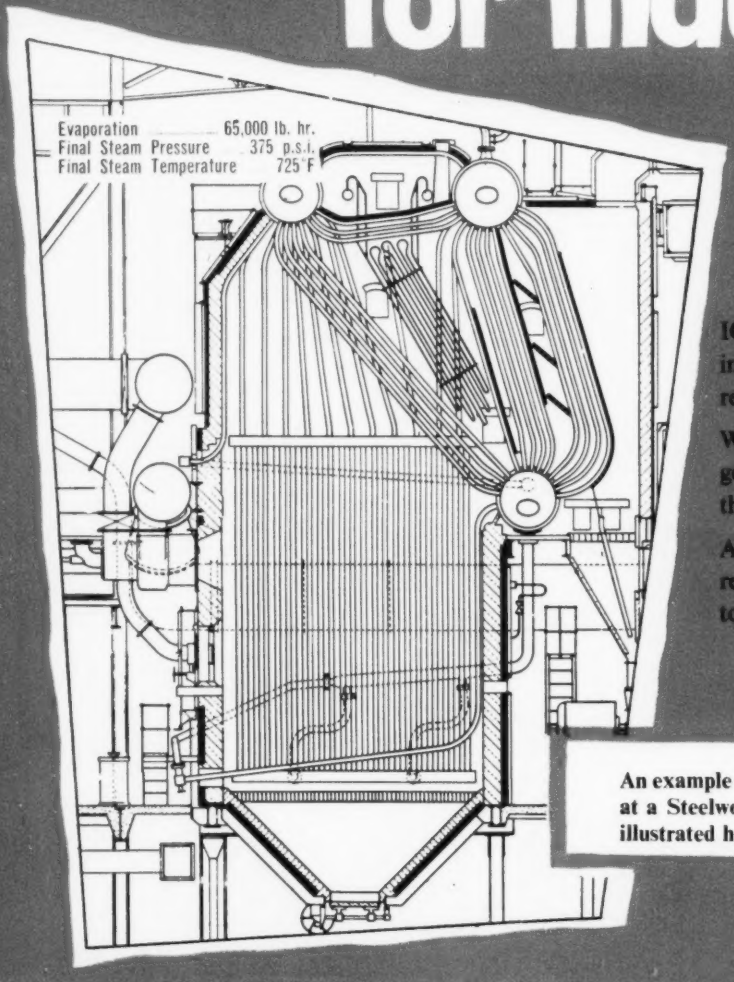

IC build boilers to suit the individual steam raising requirements of every industry.

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Allied equipment covers every requirement from fuel handling to ash disposal.

An example of an installation at a Steelworks in Turkey is illustrated here.

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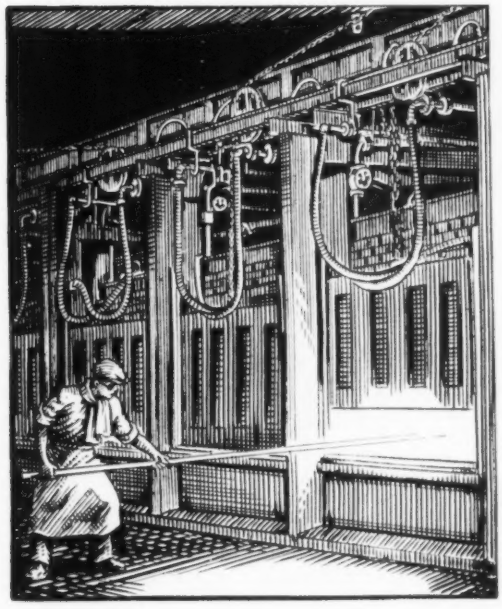

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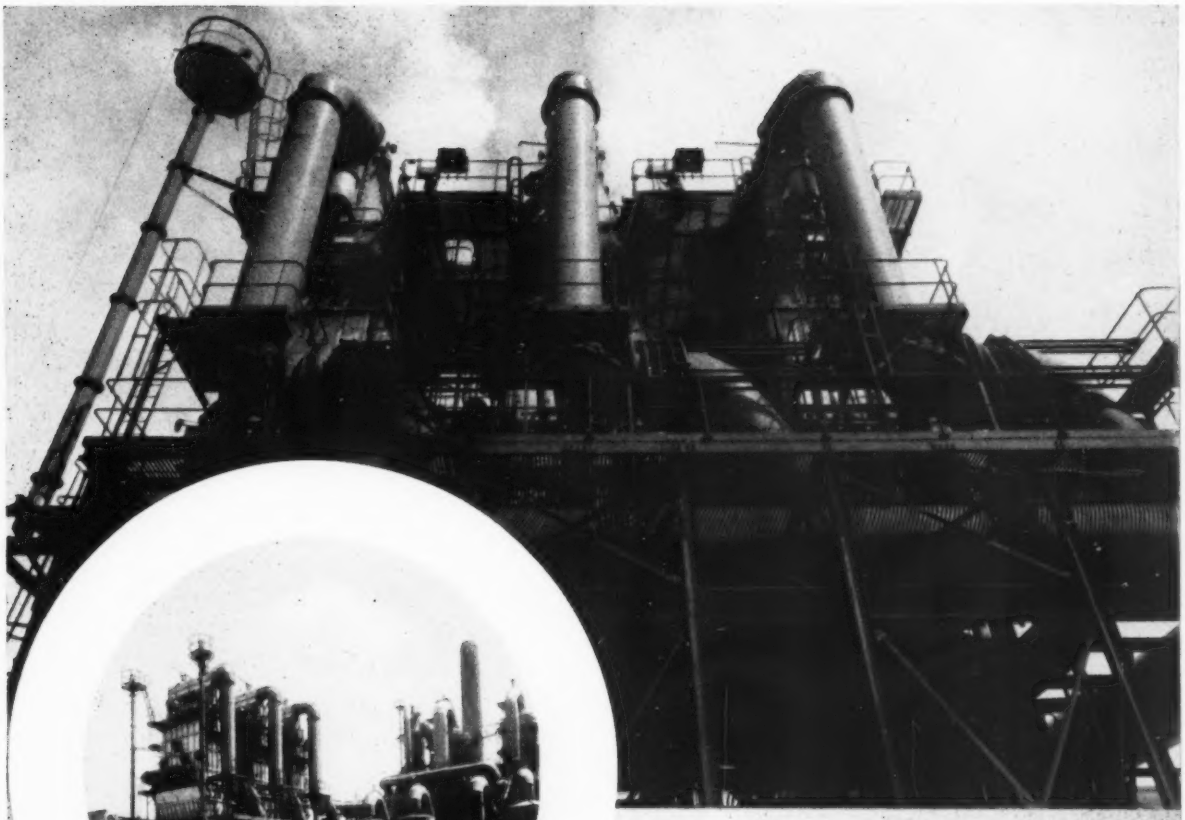

HIGH EFFICIENCY GAS CLEANING

ferro-manganese gas from blast furnaces

The photographs reproduced above show the three Holmes-Elex Electrical Precipitators cleaning ferro-manganese gas after the blast furnaces at the works of the Workington Iron & Steel Company (Branch of the United Steel Companies Limited). This installation has a total capacity of 4,200,000 c.f.h. at N.T.P.

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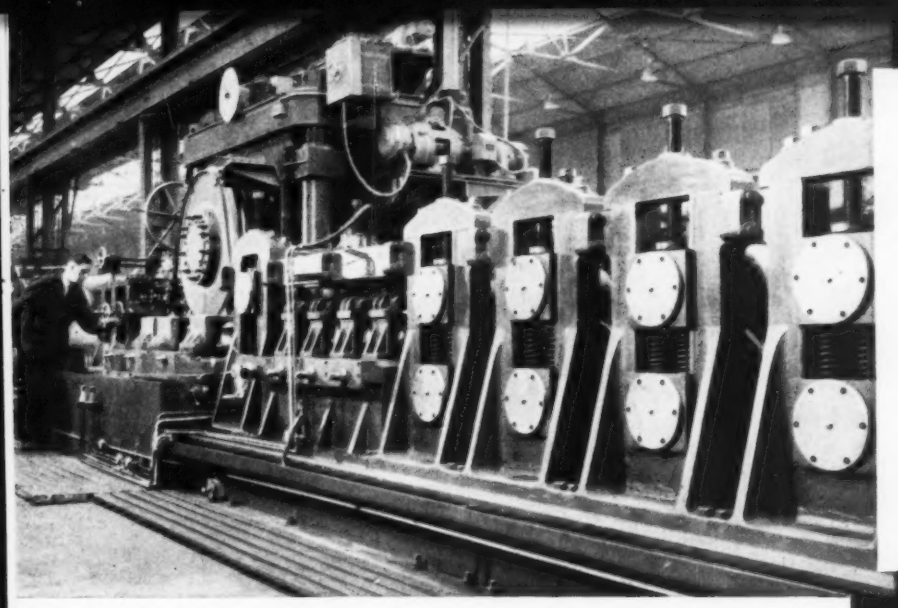
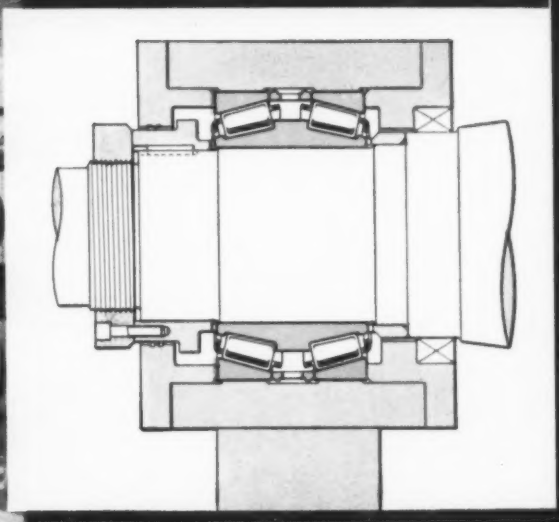




On a mill producing large electric resistance welded mild steel tubes

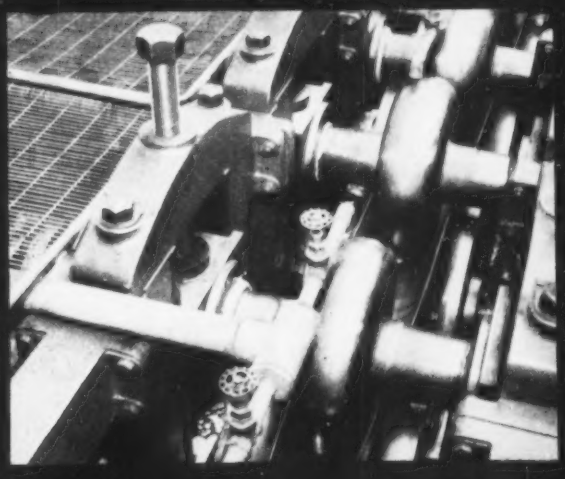
This interesting plant at Tube Products Limited, capable of making Electric Resistance Welded mild steel tubes up to $5\frac{1}{2}$" diameter and over $\frac{1}{4}$" thick, is the largest and most up-to-date E.R.W. mill in Europe.

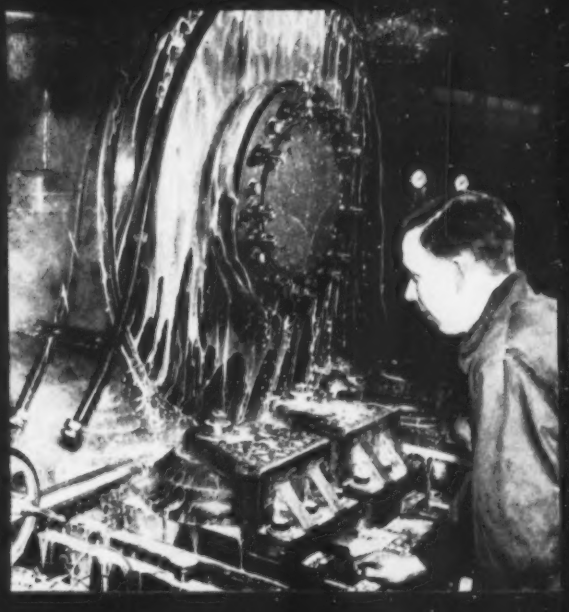
The plant, made for continuous production, was designed and constructed by the firm's own engineering department.

Above can be seen the forming-roll unit equipped with Timken bearings, while on the right the partially-formed strip is seen passing between the horizontal forming-rolls running in Timken bearings, mounted as shown in the drawing.

The lower view shows the welding stage of the E.R.W. process and here again the main spindle carrying the electrodes runs in Timken bearings.

British Timken, Duston, Northampton, Division of The Timken Roller Bearing Company. Timken bearings manufactured in England, Australia, Brazil, Canada, France and U.S.A.





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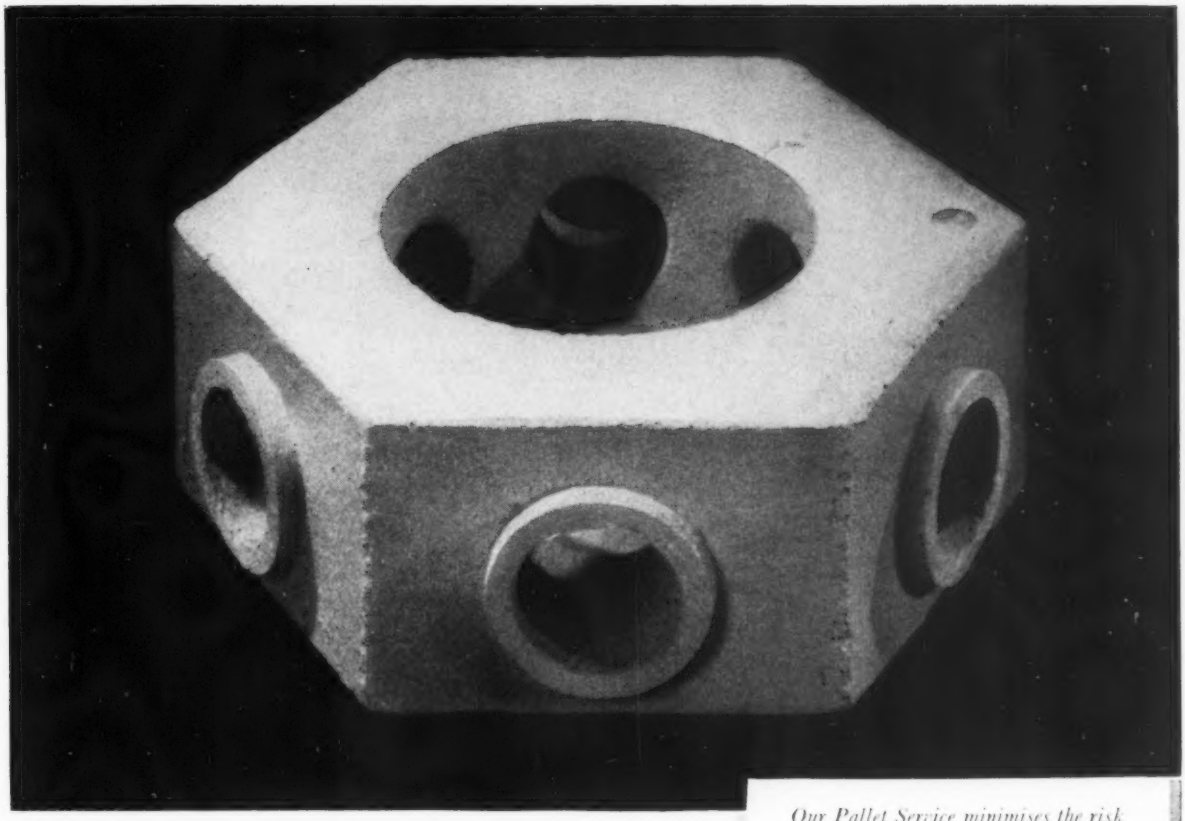

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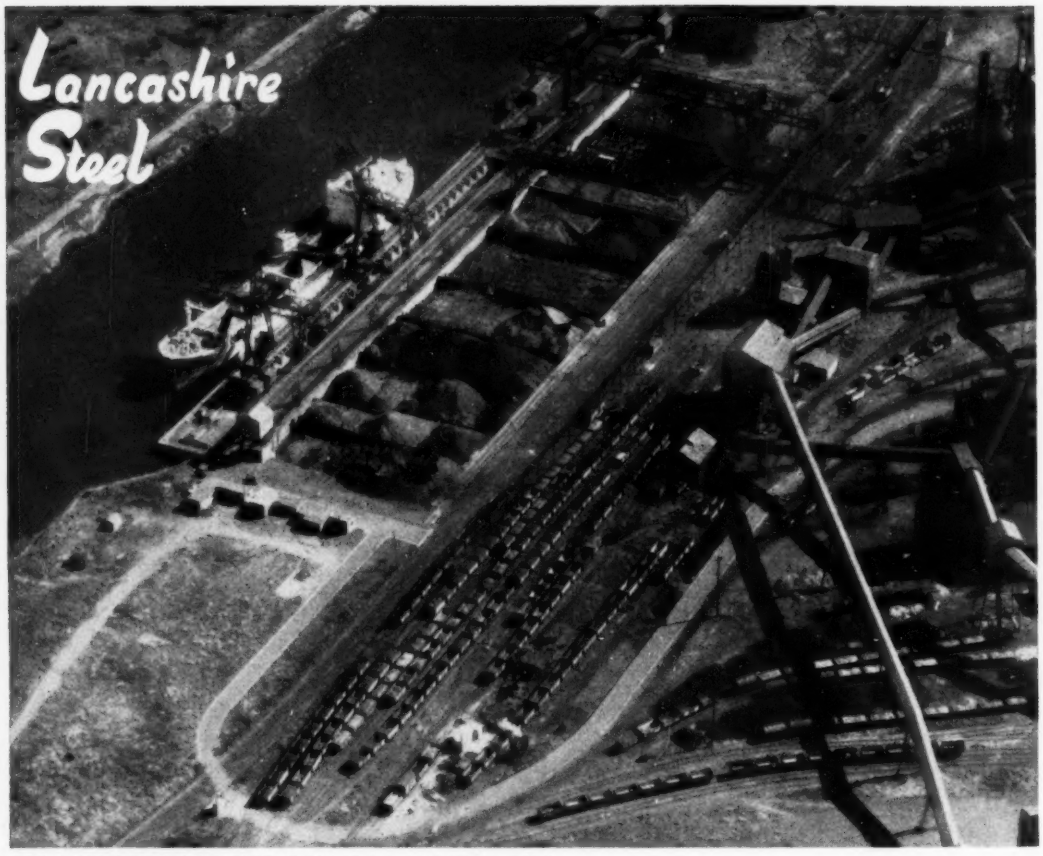

AERIAL VIEW OF THE UNLOADING WHARF—*Photograph by Aero Pictorial Ltd.*

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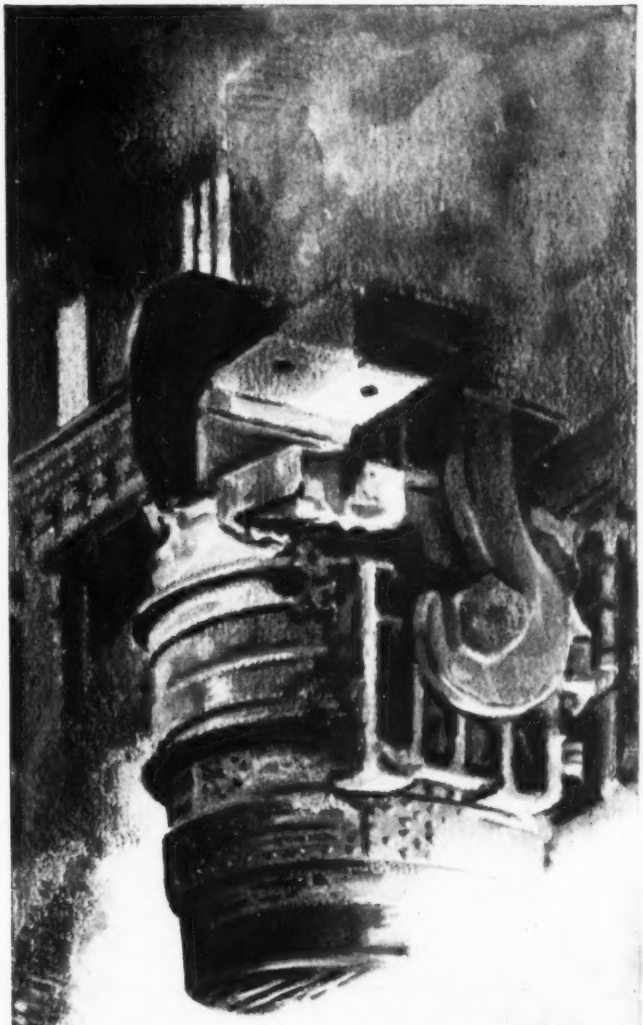

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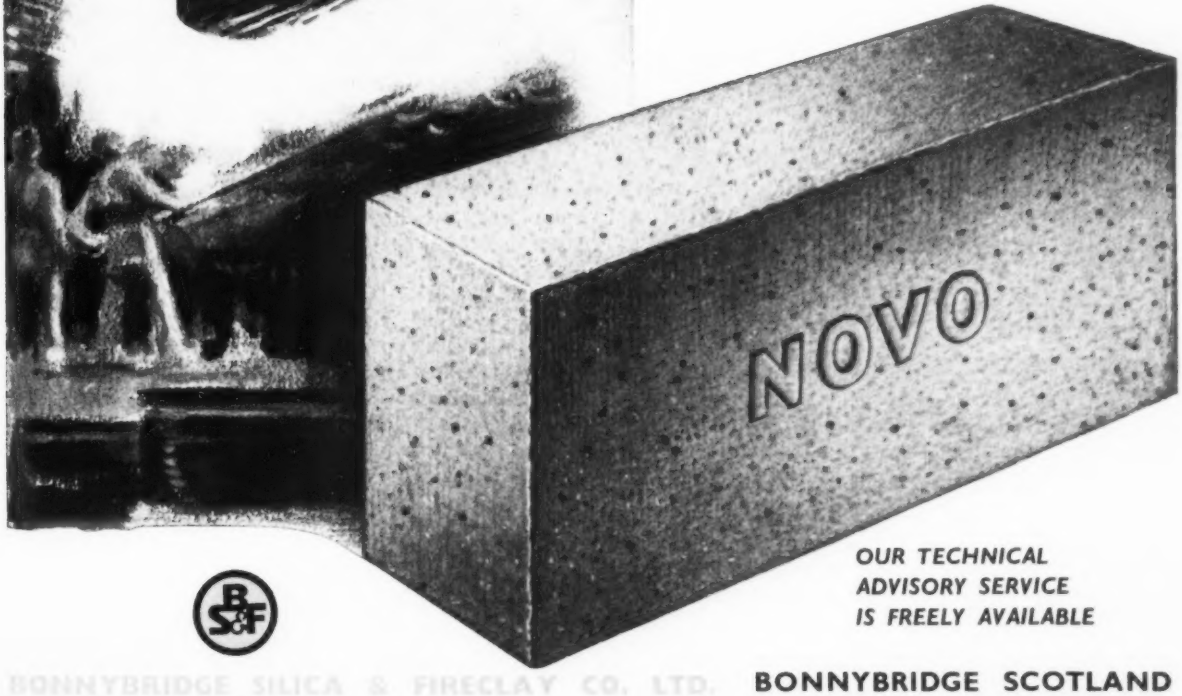

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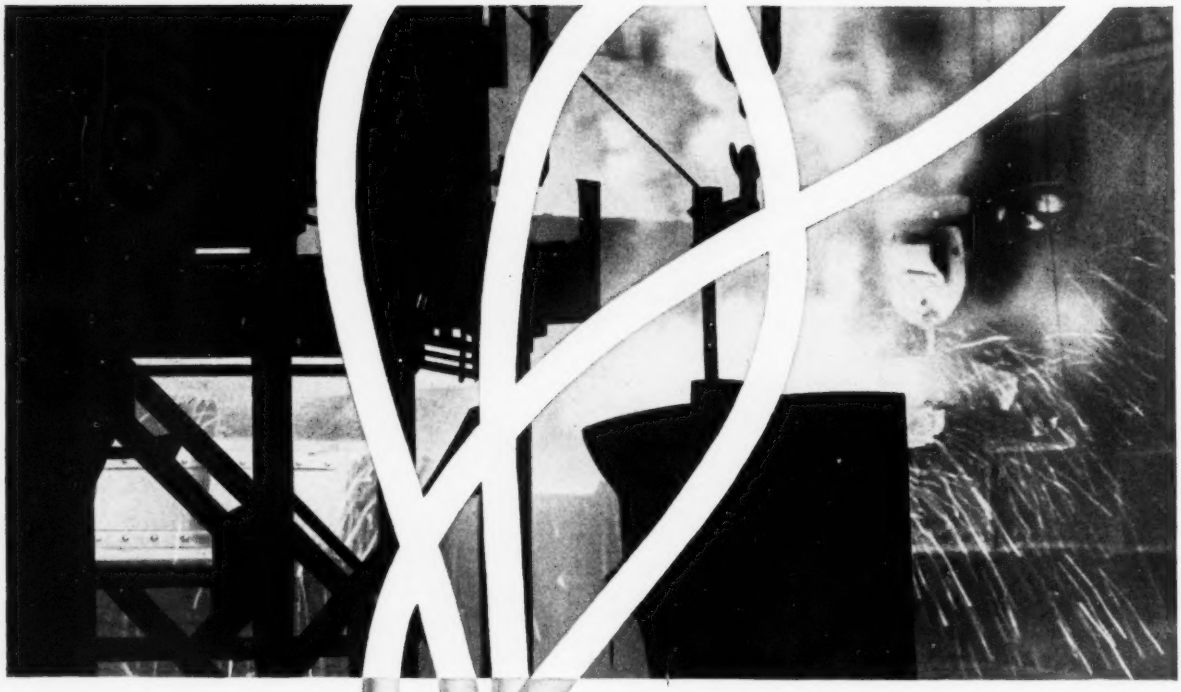

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On the opposite page we show the principal grades of OUR SPECIALLY TOUGHENED SG ROLLS and OUR SUPER METAL MOORALLOY ROLLS but each of these quality ranges are again subdivided to suit requirements.

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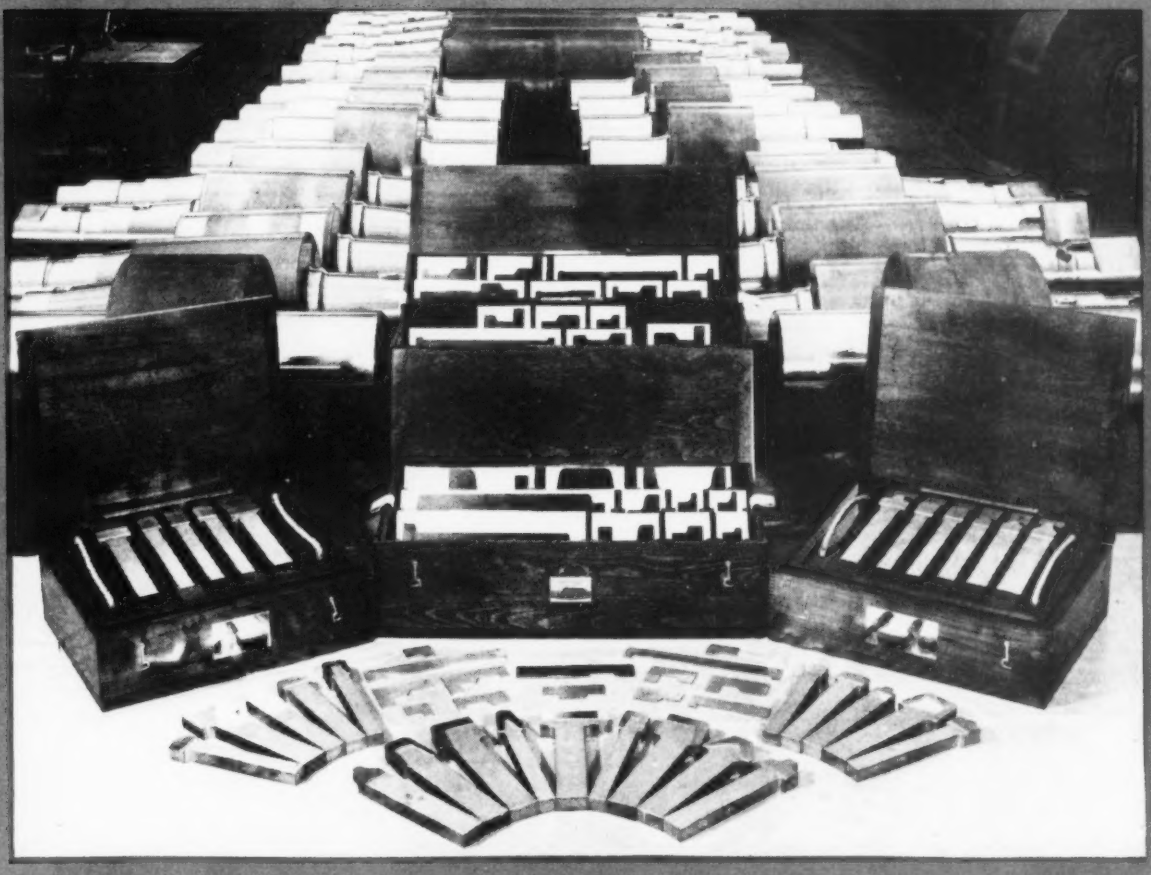

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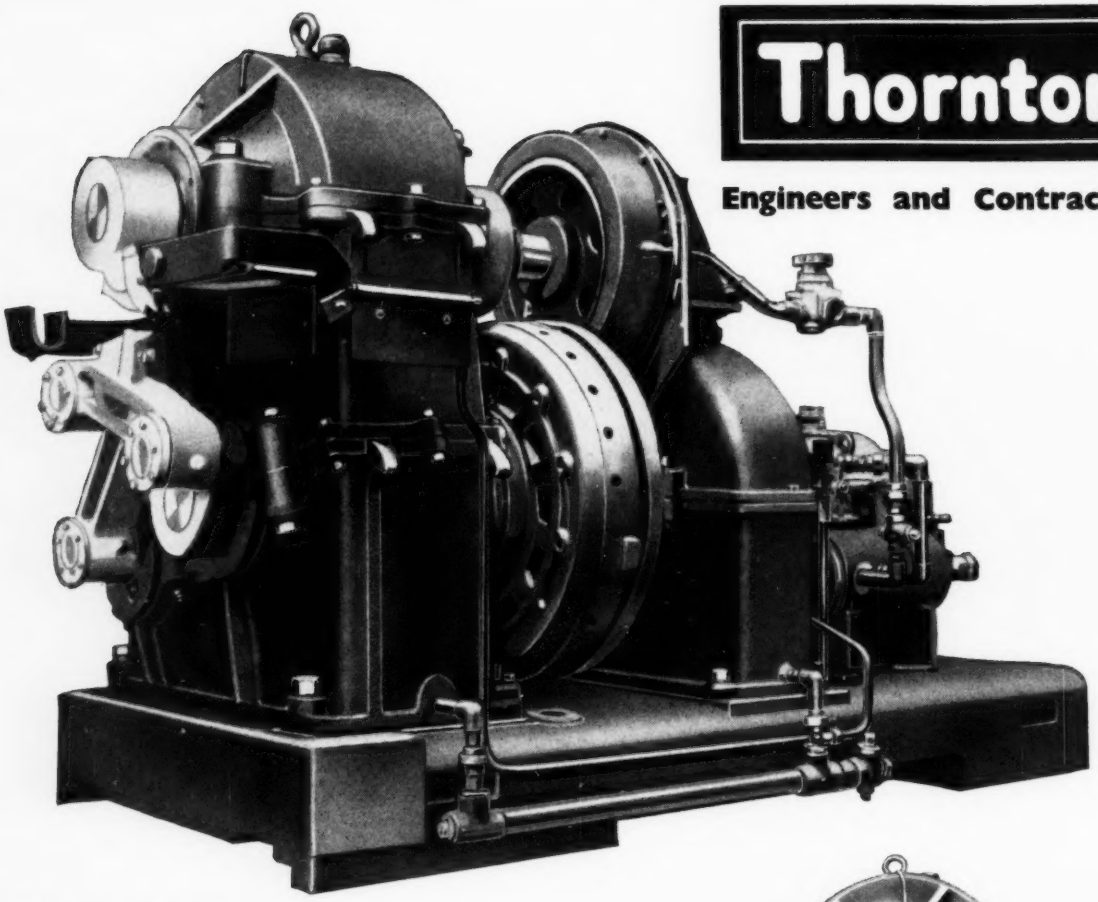

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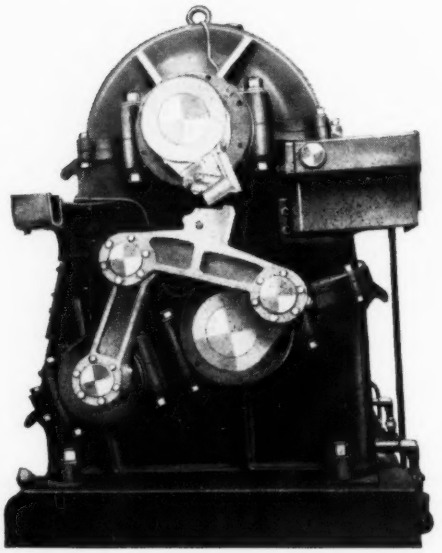

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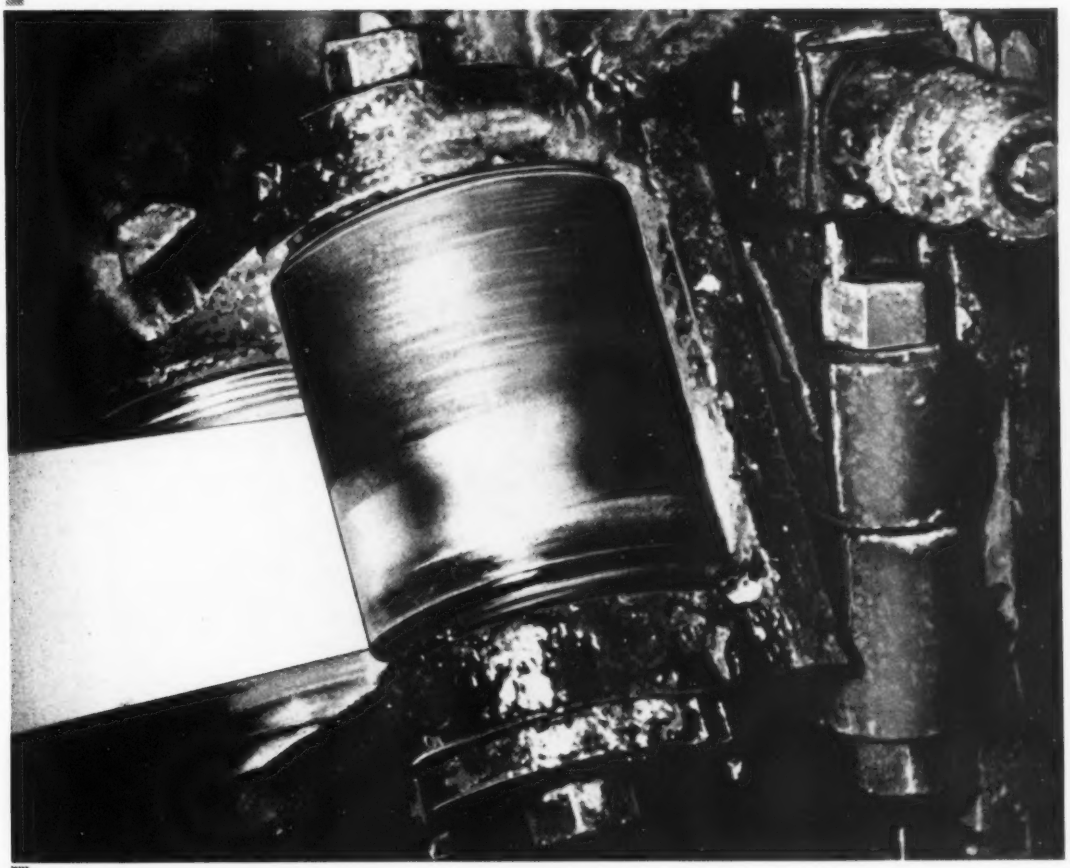

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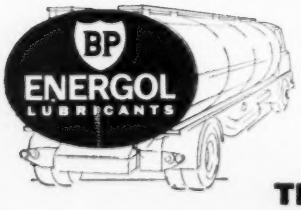

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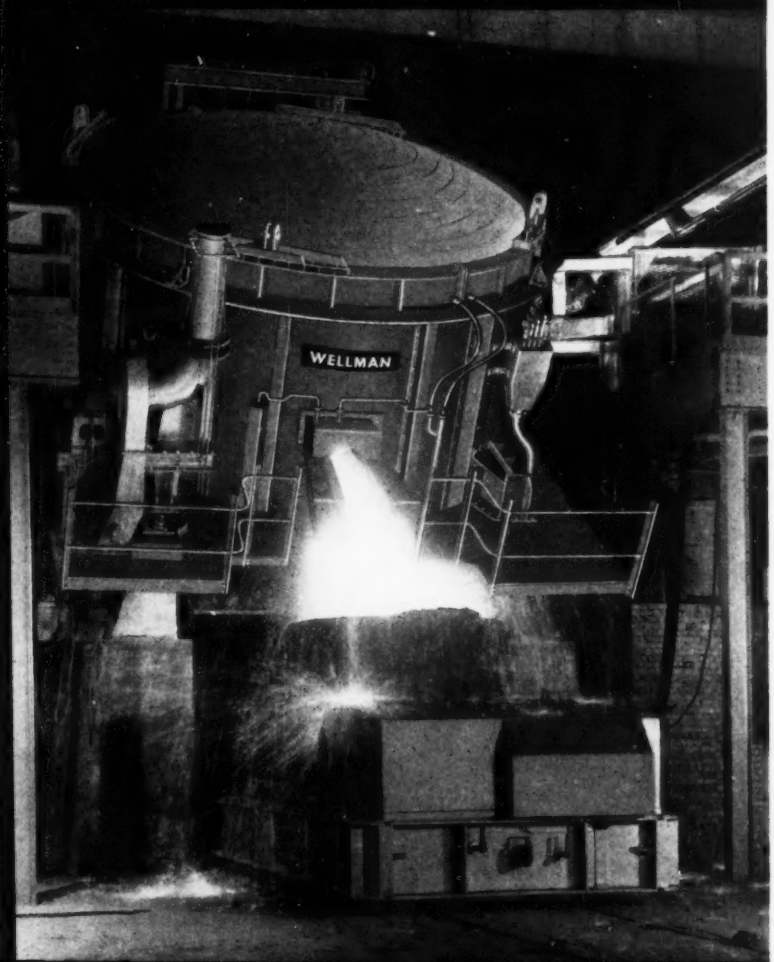

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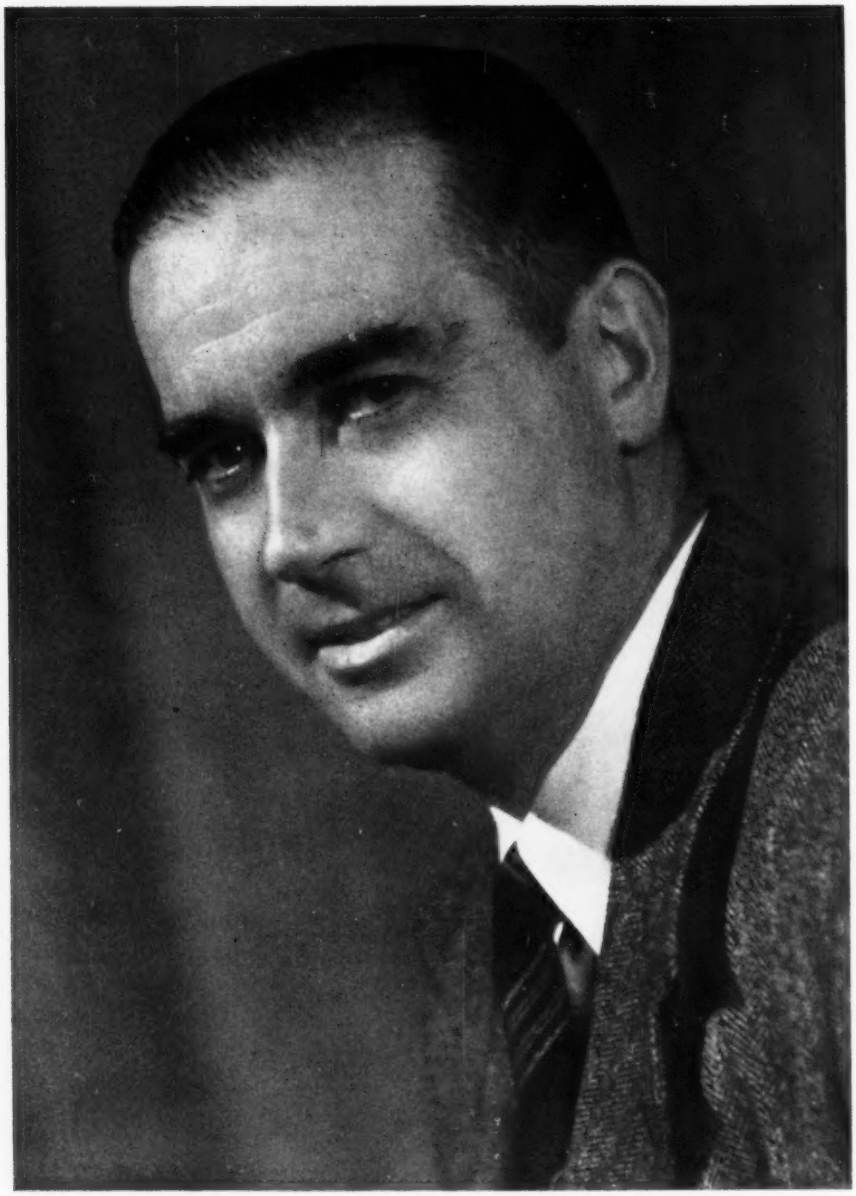
L. NORTHCOTT, D.Sc., Ph.D., F.R.I.C., F.I.M.

LESLIE NORTHCOTT received his academic training in the metallurgy department of the University of Birmingham immediately after the First World War. He joined the staff of the then Research Department, Woolwich, in 1924 under Dr Harold Moore, initially to study the casting of brass ingots on behalf of the BNFMRA. Later, and partly as a result of the work of The Iron and Steel Institute Committees on the Heterogeneity of Steel Ingots and on Steel Castings, studies were made in these fields. During the Second World War his section was housed at the National Physical Laboratory, Teddington, and in 1947 Dr Northcott returned to Woolwich on his appointment as superintendent of metallurgical research. He was promoted to principal superintendent in 1954 and with the amalgamation of the Armament Research Establishment with the Armament Design Establishment to form the Armament Research and Development Establishment at Fort Halstead in January 1955, Dr Northcott was appointed principal superintendent and head of the materials division in the combined Establishment.

During his long association with the ARDE and its forerunners, Dr Northcott has been engaged in a wide variety of investigations in both the ferrous and non-ferrous fields, the results of some of this work being published by the Institute and The Institute of Metals in a series of papers. These deal with the casting of steel ingots and the study and effect of different casting methods on properties, structure, and segregation; temper brittleness in alloy steels; centrifugal casting of steels, copper-base alloys and aluminium-base alloys in chill and sand moulds; powder metallurgy; veining and sub-boundary structures; casting techniques for non-ferrous alloys; titanium alloy steels; extrusion of light alloys; crystal structure, segregation, and deformation of copper base alloys, and thermal fatigue. He has also written a book on molybdenum.

Dr Northcott has visited Germany, France, USA, and Australia, to study metallurgical works and research establishments in these countries.

He is a member of Research Committees of the British Iron and Steel Research Association and the British Steel Castings Research Association and a member of Council of The Institution of Metallurgists. He became a member of The Iron and Steel Institute in 1924 and was elected an honorary member of Council in 1958.



L. Northcott, D.Sc., Ph.D., F.R.I.C., F.I.M.
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New processes in an integrated iron- and steelworks layout

W. F. Cartwright

The text of a lecture delivered by Mr W. F. Cartwright, D.L., J.P., President of The Iron and Steel Institute, when he received the Federico Giolitti Steel Medal at the Joint Meeting of the Associazione Italiana de Metallurgia and the Institute in Milan on 30 May 1960

IN THE PAST FEW YEARS, many metallurgical developments have taken place which have resulted in major changes in the processes of manufacture of iron and steel, but I do not feel that full advantage has been taken by engineers engaged in steelworks layout of the opportunities these changes provide for improving the layout and the handling of raw materials. I propose, in this lecture, to discuss ways in which the layout of a new integrated iron- and steelworks might be so arranged as to reduce the capital cost involved in railway tracks, roads, and land, usually involved when laying out a works in which the departments are completely separate and connected by road and rail and, as a consequence of this improved layout, to discuss how costs for handling materials might be reduced.

The handling of materials from one department to another and within each department is a major cost in the manufacture of iron and steel. For several generations the only methods involved were belt, standard-gauge railway track, overhead cranes, and roller gear. With the rapid development of earth-moving machinery and road transport, new methods have become possible. In order that I may be able to bring out the points I have in mind, I propose to describe how a typical iron- and steelworks manufacturing cold reduced sheets might be redesigned in the light of recent technical progress.

Let us suppose that such a works consisted of a blast-furnace and coke-oven plant utilizing a local coking coal and seaborne ore, that the conversion from coke and iron ore to pig iron was by the use of blast-furnaces, with all the techniques now available to the blast-furnace manager, that the molten pig iron, together with 25% scrap, mainly arising within the works or from the works' customers was converted into steel by the LD process, and that the resultant molten steel was converted into slabs on continuous casting machines, and from thence into hot strip and finally into cold reduced strip to be converted into cold reduced sheets. Let us also assume that a certain proportion of this cold reduced sheet is to be converted into cold reduced tinplate.

Dealing first with the dock, should a works be lucky enough to receive ore from only one source, I am sure that the modern method would be to use a fleet of self-discharging ships. For any haul of over 2000 miles they would probably carry 50000–60000 tons each, and with self-discharging gear would be capable of discharging at 4500 tons/h as against probably 3000 tons/h by conventional means.

Most of the iron-ore mines in the world today produce a very high percentage of fines, and such a dock plant should deliver via a weighing and automatic sampling unit, a crushing and screening plant, followed by stocking facilities for rubble ore and fine ore. Rather than use expensive transporters for recovery from stock, I think there is a lot to be said either for the use of the Robbins Messiter bedding plant, or for a tunnel under the stockyard, through which the stock could be recovered at least partially mixed. Simple earth-moving machinery can then be used to feed into the tunnel.

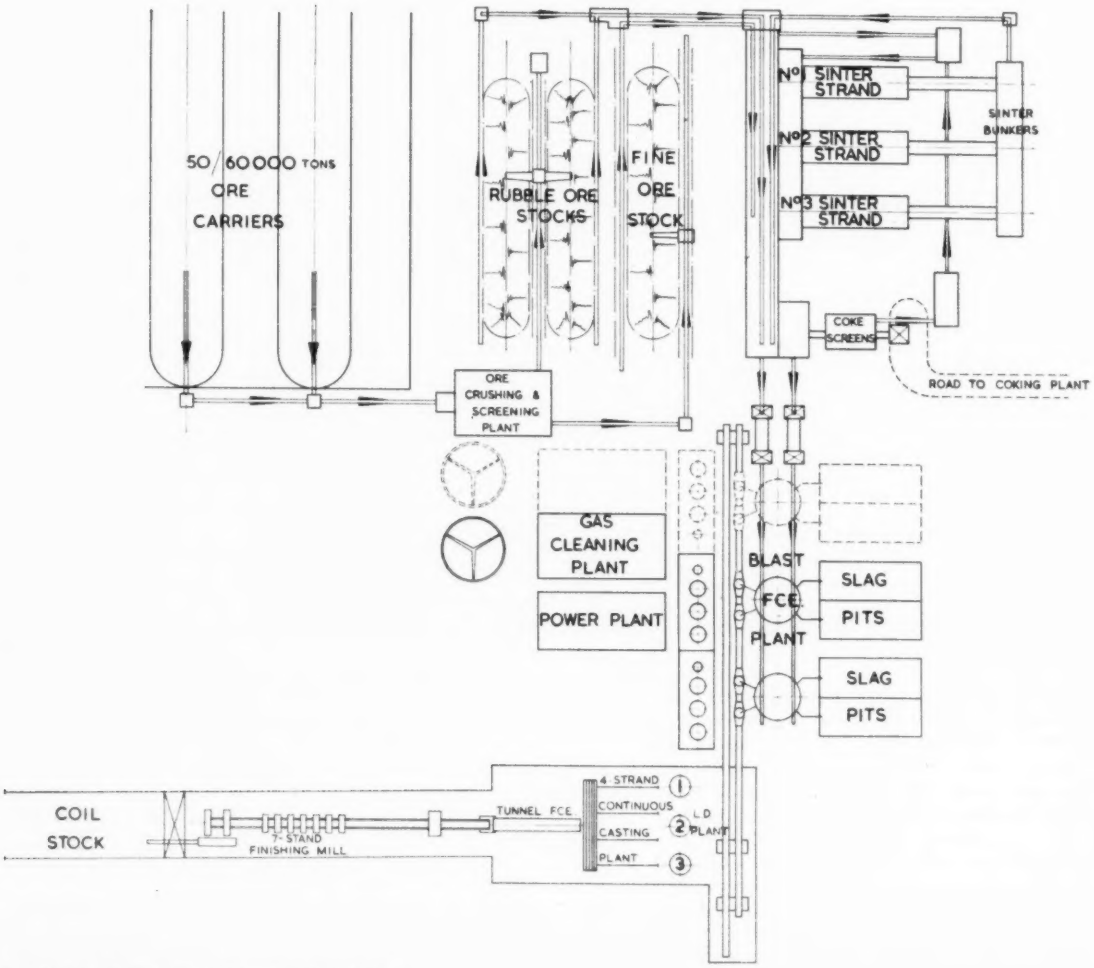
The sinter plant and the ore yard would be linked by belts, but any excess stock due to abnormal conditions would be handled by very heavy road transport vehicles of the self-dumping type, each vehicle carrying perhaps 50 tons of ore, recovery being by face shovel.

Blast-furnace plant of the past normally received coke by belt, and the main screening plant was situated at the coke ovens. In the plant of the future, I suggest that the coke ovens might be sited at the most convenient spot for coke ovens, irrespective of the location of the blast-furnaces and certainly up to a mile distant, but at the place most easy to service the coke ovens with coal, whether the coal comes by road vehicle or rail vehicle. The resulting coke would be carried in road vehicles, each vehicle carrying about one oven of coke and delivering it to a large crushing and screening plant at the blast-furnaces. Stocking of coke could be carried out by the same vehicles, and recovery by simple earth-moving equipment such as a face shovel, carried on rubber-tyred mounting.

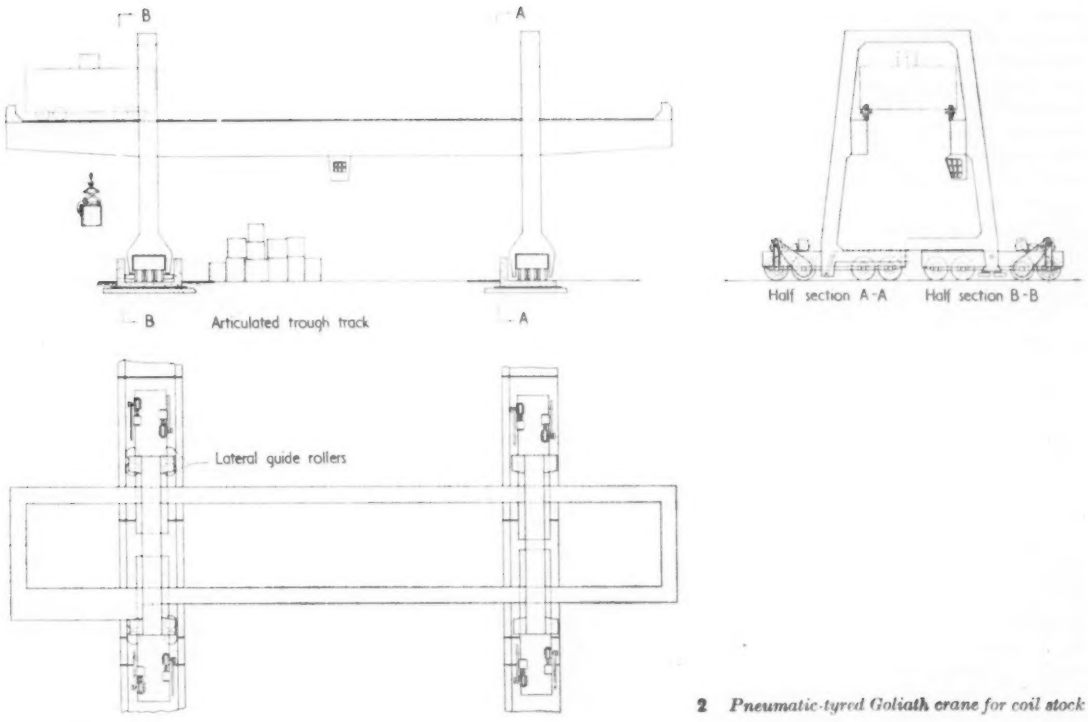
The large screening plant should be as near as possible to the point of discharge into the blast-furnace skip, and it may well be possible to eliminate the final screening now normally used on every blast-furnace plant, although a surge bunker of some sort would, of course, be necessary. By this method the degradation of coke which is so normal on belts would be reduced, the screening of stocked coke would be carried out at the blast-furnaces, and the resultant coke delivered to the furnace top would be of better quality.

Normally blast-furnaces are laid out at a considerable distance from the open-hearth or Bessemer plant, and transfer from the blast-furnaces to the steel-plant mixer takes place by means of standard-gauge railway track. With the introduction of the LD process, with its great saving in space compared to the OH, it will be possible to build single mixer cars, carried on abnormal track, perhaps several tracks, into which each furnace will tap. A single mixer car might hold 400, 500, or 600 tons, the car being self-propelled to the LD bay. With modern control of blast-furnace operation, it should be unnecessary to install any mixers, the single car being used merely as a storage vessel to bridge the gap between taps.

Modern LD plants will probably hold about 200 tons per vessel and there should be little difficulty in laying out a blast-furnace plant of two blast-furnaces with an LD plant to one side, so that a further blast-furnace or a further LD vessel could be added without interfering with the operations of either.



1 *Layout of an integrated iron- and steel plant*



2 *Pneumatic-tyred Goliath crane for coil stock*

Since slag is a valuable credit, it could be used in most cases for roadstone and other purposes. The lay-out of the slag plant must clearly be very carefully studied, because the simple pit, which has recently become fashionable, tends to produce a porous slag unsuitable for use as aggregate, but with some study of the layout of the pits, slag could be cooled in such a way as to retain its density.

It seems probable that the large blast-furnace of the future will have two iron tapholes and two slag tapholes, the slag tapholes being on either side of the back, and the iron tapholes being on either side at the front.

Figure 1 shows the relationship of the coke screening plant, the blast-furnaces, and the steelmaking plant.

As yet, no works has really been laid out from the start with a continuous casting plant only. Most continuous casting machines have been added to an existing works which already has a primary mill. If a large LD plant is to be designed to fit a continuous casting plant, it is possible that the ladles of molten steel would have to be drawn off in, say, 100-ton lots. This should present no difficulty in the modern vessel, which is fitted with a taphole. The continuous casting strands should be of adequate capacity so that they never hold up the steel plant, and this will mean a relationship between the continuous casting bay and the LD plant, which has not yet been seen in practice. Again, Fig.1 shows how this relationship might be arranged.

Since in any strip mill high weight per inch width, and in any rod mill high weight per coil, is of vital importance, the designers of continuous casting plant must strive towards longer and longer slab and billets, and this, I am convinced, will mean the introduction of bending rolls, not only for 2 in. billets as at Barrow-in-Furness, but also for quite thick slabs, which may involve the construction of quite elaborate large-radius bending plant. The resulting slabs which will issue on the horizontal, rather than on the vertical, as in most continuous casting plants today, should then be capable of being rapidly reheated in some form of tunnel furnace so that direct rolling can be achieved. Since constant dimension of slab or bloom is an important requisite in continuous casting plant operation, it would seem that the first stand of any strip mill working purely with a continuous casting plant should be like a small universal mill, capable of converting one standard slab width thickness into a fairly large variety of slab widths.

Hitherto, metallurgical requirements in the hot strip mill have governed the layout. On the one hand, the metallurgist has demanded a very close tolerance on finishing temperature when the piece is entering the close-coupled six finishing stands, and on the other hand, he has demanded a low temperature when it is entering the coilers. Owing to the necessity of coming out of the slab furnaces at a high temperature so as to be able to carry out the reduction necessary in the roughing mill, it has been important to cool down the piece before entering the finishing mill, otherwise too high a finishing temperature was brought about. It has been necessary to keep the coiling temperature well down if carbide difficulties were not to be encountered. These two requirements have resulted, in the normal strip mill, in a considerable gap between the last roughing stand and the first finishing stand, and between the last finishing stand and the first coiler. It is interesting to speculate whether the invention of the open coil annealing process, accompanied by the use of wet hydrogen as a decarburizing gas, with its ability to

lower the carbon to extremely low limits, may not remove the necessity for the distance both between the roughing mill and the finishing mill, and between the finishing mill and the coilers. Should a coil be destined for decarburization in an open coil annealing furnace, using wet hydrogen, it should be possible for the reversing rougher ahead of the finishing mills only to have a gap between the mill and the finishing stands equal to the length at the last thickness. An efficient design would be a universal reversing roughing mill and, say, seven or eight finishing stands, a piece going into the finishing mill far hotter and thicker than it does at present.

On the outgoing side, at the moment nobody has succeeded in making a piece, say 0·083 in., stay on any roller table at a speed above 2200 ft/min. If coiling temperature were no longer a real worry, it might be possible to shift the coilers to within a few feet of the finishing stands and finish at speeds of, say, 3000 to 3500 ft/min, thus vastly improving the output of the mill and decreasing trouble with rundown.

One of the problems in the past has been what to do with scrap arising at various points. The invention of the Marrel lorry, with its ability to transport its own skips without the help of an overhead crane, has made it extremely simple to recover mill scrap from wherever it arises, and to take it direct to the sinter plant in these skips. Thus it does not seem to me that it should really be necessary to have any railway tracks at all from coke and ore right through to finished hot strip.

As much as we would all like to see the departure of the sulphuric acid pickling line, there seems little hope of this at the moment. It has had numerous additions such as the McKay processor, the skin pass mill, and additional tanks, but still it remains the sole mass-production method of removing scale. However, one change might take place in that coils may be stored between the end of the strip mill and the pickle line in an open-air rubber-tyred gantry, such as has been suggested by W. S. Atkins (Fig.2).

Probably in such a plant, the hot strip, after coiling, would be plunged immediately into a cold water bath in the interests of good pickling. Coils could be removed by the overhead Goliath-type crane, and put into stock and recovered from stock long before rusting became a serious matter. It is interesting to note that should the use of decarburization become general, it should be possible to build a five-stand mill where a four-stand mill is now used, and use a thicker hot band for a given cold-reduced gauge without fear of trouble from grain size, which now occurs when using too high a percentage of cold reduction.

Much of what I have said so far from the hot strip mill onwards has been based on the assumption that the idea of reducing the carbon to very low limits in the open coil annealing furnace in an atmosphere of wet hydrogen will succeed. If it succeeds it will enable deep-drawing steels to be made from bottle-top grade ingots, without the use of low carbon ferromanganese, with the very high Fe yield associated with bottle-top steel, and without any worries about top cut discard. However, changing over to decarburization halves the output of the open coil annealing furnace, and some development work will probably have to be done to speed this up again.

It seems likely that the works which has been described would ship most of its product in coil form after annealing and skin passing. In the tinplate section, such a plant might really be extremely compact, consisting of pickling, cold rolling, open coil annealing with carbon reduction, temper passing, and electrolytic tinning.

To sum up, I would suggest that iron- and steelworks of today have too long been in a rut in so far as layout is concerned. They could be made much more compact, railways could be largely eliminated, and more use could be made of road transport. Some developments in the annealing field may have far-reaching effects on the future design of the hot strip mill, and indeed the cold reduction department as well, but in any case, whatever the works which is now being laid out, it should be possible to effect considerable savings in capital and operating cost by considering the use of new techniques and new methods in handling raw materials.

The dynamics of the blowing process

T. Kootz

SYNOPSIS

Equilibria and non-equilibria are considered first in the basic Bessemer converter and the open-hearth furnace, and the course of dephosphorization and carbon elimination in these processes is examined. The characteristics of the oxygen top-blowing process, and various possible effects of the oxygen jet on the bath and on the sequence of reactions, are described. The requirements and advantages of the rotor processes are then discussed, and the characteristics of all four types of processes summarized. 1880

EQUILIBRIA AND NON-EQUILIBRIA

SOLID AND LIQUID PHASES obey the same laws of thermodynamics. While non-equilibria and undercooling are, however, normal conditions for solid body reactions, it is often assumed that equilibria or near equilibria are attained in steelmaking furnaces between metal and slag.[1,2] The attempt, however, to connect the mechanics and metallurgy of the steelmaking processes is based on the assumption that, depending on the mechanical circumstances, more or less substantial metallurgical differences, i.e. more or less substantial non-equilibria can occur.

The basic Bessemer process

Probably no steelmaking process offers a better prerequisite to the achievement of equilibria between gas phase, metal, and slag than the basic Bessemer process. The blast not only gives rise to rapid and vigorous circulation but also causes regular stirring of the bath.[3] A spinning movement is superimposed on the circulatory movement of the bath.

Even in this 'supermixer', however, there are traces of non-equilibria. Although there is finally a distinct temperature relationship between the iron content of the slag and the phosphorus content of the metal, the lumpiness of the lime also clearly affects the phosphorus and oxygen contents.[4] Although, depending on the ferrous oxide content of the slag of normal composition and on its basicity, the oxygen contents of the steel are throughout such as are required by the activity of the ferrous oxide in these slags between lime saturation and miscibility gap,[5] they increase under slags richer in silica for the same composition in the limited ternary system $FeO+MnO–CaO–P_2O_5$ to an unexpected extent (Fig.1).[2] In the case of a miscibility gap narrowed by silica, the opposite should be the case. Slags richer in silica should possess a lower activity of the ferrous oxide.

The further observation that high-manganese heats lead to higher carbon contents and lower oxygen contents at the end of refining (Fig.2)[6] than low-manganese heats may be explained by the following concept, in the region of the blast, oxygen is picked up, and carbon elimination occurs only here where there is contact between iron and the blast. At the same time, the final carbon and oxygen contents are governed by the oxygen pressure of the primary product of oxidation[7] which consists of varying amounts of ferrous and manganese oxides, depending on the manganese content of the metal. Dephosphorizing is, however, carried out under the finishing slag mainly in the upper regions of the bath beyond the confines of the blast. The metal bath is there deoxidized by the phosphorus as soon as a limey and fluid slag is obtained.

With high silica contents, the finishing slag does not become fluid until later (the transition from the system $FeO–CaO–SiO_2$ to the system $FeO–CaO–P_2O_5$). The phosphorus encounters in the iron high oxygen contents emanating from the region of the blast and is no longer able to deal with them.

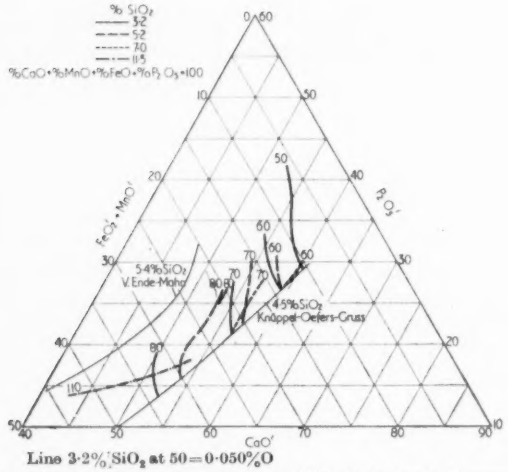
If this concept is valid, then there are no grounds to expect that the washing effect of the finishing slag can determine the final oxygen content of the steel after dephosphorization is completed or that it would attain equilibrium between the steel and the slag.

After all, the course of the reaction of carbon elimination and dephosphorization is determined by the reducing effect of the carbon which would fundamentally be expected for a reduced partial pressure of carbon monoxide in the waste gas (Fig.3).[8]

The OH furnace

If, therefore, equilibria are not attained even in the

Manuscript received 3 August 1960.
Herr Dir. Prof. Dr Kootz is with August Thyssen-Hütte AG, Duisburg-Hamborn, Germany.

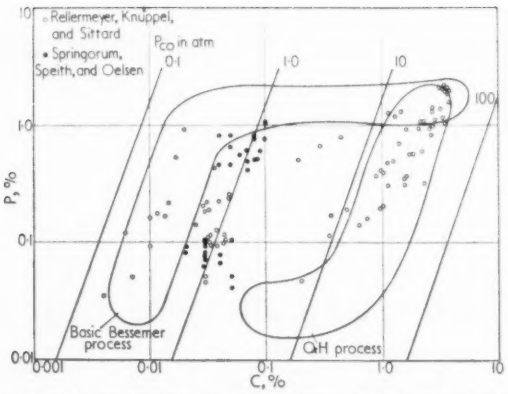


1 *Lines of equal oxygen content* (10%$^{-3}$) *in basic Bessemer steel, under slags of varying silica content*

basic Bessemer converter, what are the chances in the OH furnace?

Fortunately for the OH process, in contrast with the basic Bessemer process (Fig.3), dephosphorization is not limited to such low carbon contents as would be expected in the case of equilibrium below 1 atm CO. Otherwise the carbon content would have to be oxidized down to below 0·03% in order to attain less than 0·05% phosphorus. Such low phosphorus contents are attained in the OH furnace when refining basic Bessemer pig iron by the time about 0·6% carbon is reached. This means that, in the OH furnace, dephosphorization proceeds at about 20 times higher carbon contents than would be expected according to the equilibrium (under lime-saturated slags). This discovery can also be expressed thus: in contrast with the converter, carbon elimination in the OH furnace is subject to a delay in the boil[9] due to the time required for formation of minute carbon monoxide bubbles, and proceeds beneath the slag blanket only when oxygen supersaturation is so high that it overcomes an excess pressure of about 20 atm CO.

Carbon elimination in the OH furnace sets in at the hearth bottom[10, 11] as it is subject to the delayed boil under the slag. The thinner the layer of slag, the smoother the process of carbon elimination. The rising



3 *Possible scatter band of the progress of dephosphorization with top-blowing*

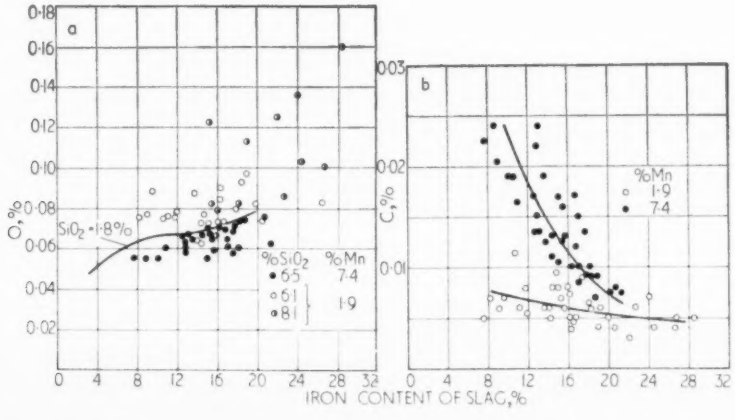
CO bubbles deoxidize and cause movement of the bath.

If carbon elimination set in at the slag/metal interface in an uninhibited manner, then there would be no dephosphorization in the OH process before or during carbon elimination and, moreover, there would not be the necessary bath movement even during carbon removal. The basic OH process would never have been born.

It is quite certain that in the basic Bessemer process, uninhibited carbon removal in the region of the blast compels the well-known reaction sequence but that even there an equal degree of oxidation between metal and finishing slag is not attained although the bath is very vigorously stirred by the blast. On the other hand, carbon elimination in the OH furnace occurs at the slag/metal interface only in association with a delayed boil and sets in at the hearth bottom. Consequently, there is a marked oxidation gradient between metal and slag in the OH furnace and hence this furnace can be heated to serve a useful purpose. Carbon elimination is the agent of bath movement. The differing dynamic and metallurgical conditions of both processes can be most clearly contrasted in the change in the sequence of the carbon and phosphorus reactions.

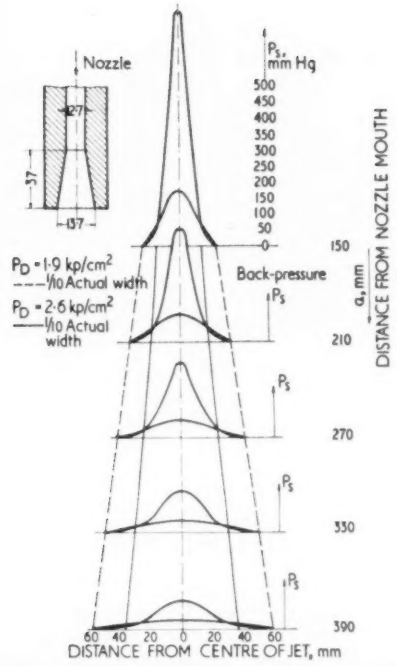
The oxygen top-blowing process

For the new oxygen top-blowing process, a bath-stirring effect was first ascribed to the blast. According

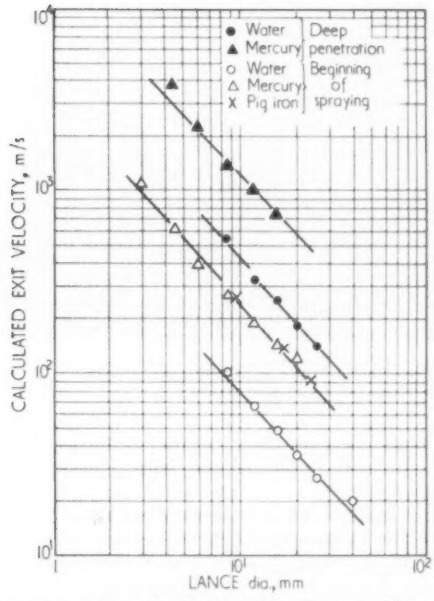


2a O *contents of iron in relation to iron content of slag for heats of varying* Mn *content*

2b *Adjustment of the* C *contents of the iron to the* [Fe] *content of the slag under slags of varying* Mn *content*



4 *Back pressure distribution* P_S *up a diffuser nozzle with two different pressures.* P_D *in front of the nozzle*



5 *Increasing exit speed with decreasing diameter of lance blowing from same position at 40 cm distance*

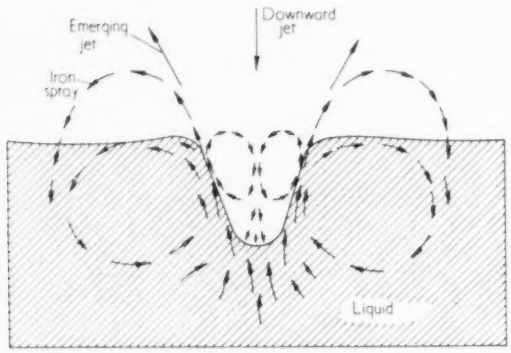
to this concept, the oxygen jet penetrates like a solid body[12] and causes bath circulation in the direction of jet penetration[13] exactly opposite to that obtaining in the bottom-blown converter. We should, therefore, expect the reaction to proceed as in the bottom-blown converter, when for instance using mixtures of carbon dioxide and oxygen, or water vapour and oxygen.[14] In this case too, bath circulation is certainly weaker than when using air blast but here again dephosphorization sets in really vigorously only after carbon elimination. The first and most important experience with oxygen top-blowing showed that bath movement is sufficient for the necessary rapid rate of reaction between metal and slag only during carbon elimination, if it is desired to maintain such short refining periods as are characteristic of the pneumatic processes. After the completion of carbon elimination, it was mainly iron which was oxidized. Dephosphorization after the completion of carbon elimination was found to be impossible without oxidizing relatively large amounts of iron at the same time. Thus, if it is desired to convert high-phosphorus pig irons by top blowing with oxygen, dephosphorization has to be completed before the end of carbon elimination. A comparison of the loss of carbon with the oxidation of phosphorus produced what at first appeared to be a curious result: that sometimes carbon elimination precedes dephosphorization as in the converter, and that sometimes dephosphorization occurs first, as in the OH process (Fig.3),[5] at least at the beginning of refining. It was tempting to ascribe the possibilities of the changes in the order of the reactions, which must be due to the more or less distinctly pronounced delay in the boil of the carbon elimination reaction, to the various possible mechanical phenomena of this new blowing process.

Effects of the jet

To understand the mechanical processes which occur with top-blowing, it was first necessary to ascertain the effect of a free gas jet top-blown on to a liquid surface.[15] In accordance with the concept forming the basis of a patent,[12,13] there is indeed a form of jet in which the jet penetrates the liquid phase more or less in accordance with its external shape. This obtains, however, only if the free gas jet exhibits laminar flow. Such flow is, however, stable only for small jet cross-sectional areas and low flow speeds. Jets used in industry are always turbulent and give rise to a broad and relatively flat impression at liquid surfaces, depending on the velocity distribution of their cross-sectional areas. These jets have an included angle of 6–7° which is almost independent of the shape of the jet exit. This is at any rate valid for jets with dimensions characteristic of top-blowing processes. For jets emanating from smaller apertures, a variation of this included angle and of the velocity distribution in the jet can be observed (Fig.4) with increasing blast rate, if the lance nozzle is in the form of a diffuser. As far as we know, this observation was first made and utilized experimentally by Metz.[16]

In the jet impingement area, which is like a concave mirror, the jet itself is directed to all sides and outward. In contact with the liquid surface, the jet transmits part of its impulse to the adjacent layer of fluid and, at certain flow velocities, entrains liquid droplets from the liquid surface at the periphery of the jet impingement area (Fig.5). With an increase in the blast rate, jet penetration becomes deeper and its angle of inclination steeper while the liquid droplets entrained in increasingly greater amounts are carried still higher with increasingly steeper ejection parabola.

A jet which does not actually penetrate, but which has its direction changed in the impingement area which it has created, can impart to the bath only a



6 *Diagram of liquid circulation when blowing intensity is increased until spraying occurs*

'flat' movement in the direction of the jet which has been directed outward and upward concentrically (Fig.6).

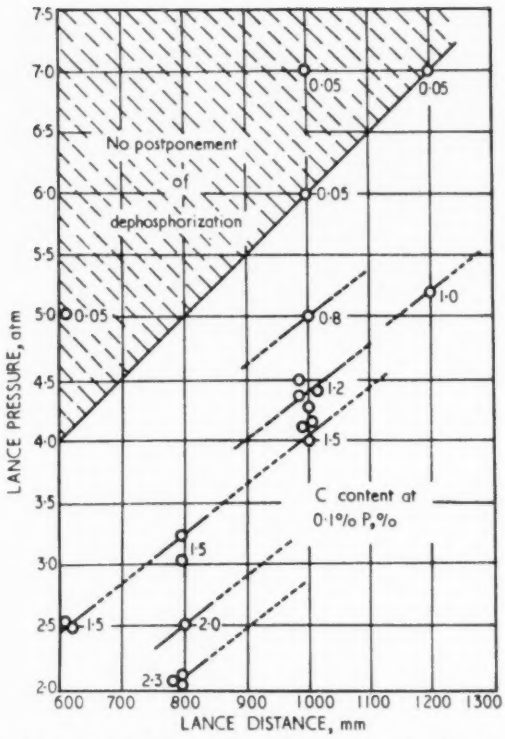
Strictly speaking, this holds good only so long as the gas at the impingement surface is not collected as is usually assumed to be the case when oxygen is blown on iron. Results of tests with industrial blowing lances on pig iron in a hot-metal ladle showed that at least the distinct beginning of the spraying of iron obeyed laws, actually depending on jet intensity, quite similar to those pertaining to the blowing of air on water (Fig.5).[15] It can further be observed that this spraying is intensified with increasing blast rate and that it is only then that the well-known brown smoke occurs. This is, no doubt, mainly due to the droplets of iron which burn and are heated up to a great extent in the oxygen jet. Furthermore, it was observed that only when this spraying effect had set in vigorously did carbon elimination start from the point of impingement.

For this reason, therefore, it would not be correct to speak of a 'reaction centre' since all the oxygen is not caught at the impingement point, much of it coming from the sprayed iron above the bath surface and being transmitted to the bath on falling again.

The carbon elimination process which sets in at the point of impingement will certainly depend on the extent of the metal/gas interface, i.e. on the impact and depth of penetration of the jet; it will make use not only of the oxygen which impacts directly but, in some cases, will utilize mainly the oxygen which is transmitted by the falling droplets of iron. The oxygen left over by the carbon is available for the phosphorus and depends on the metallic surface laid open by the jet.

If blowing is applied so that there is a great deal of spraying, a large surface of metallic iron is in direct contact with the gas jet, just as in bottom-blowing, and the more closely will the mechanical bath conditions approach those of bottom-blowing as regards the metallic surface area presented to the oxidizing gas and in terms of bath movement. Carbon elimination will be able to proceed in a relatively uninhibited manner.

The less intensive the blow or the greater the distance between the nozzle and the bath surface, the more closely will the conditions resemble those of the OH furnace where the oxygen has only limited direct



7 *Advancement of dephosphorization at various blowing pressures and lance distances in the small converter*

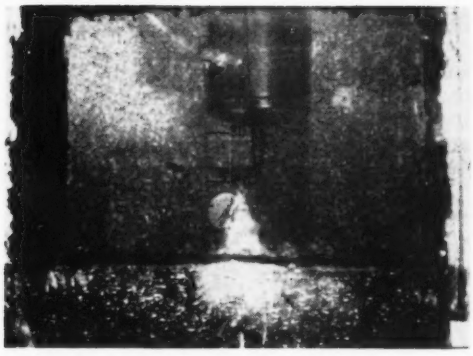
contact with metallic iron and is, to a greater extent, absorbed by the slag.

This somewhat primitive concept seems to be fundamentally correct because it was shown that the simultaneous evolution of the carbon and phosphorus reactions really leads to an increasingly pronounced advancement of dephosphorization before carbon elimination; also the higher the lance is raised from the surface, the rate of blast being maintained constant, the closer is the approximation to OH conditions (Fig.7).[17]

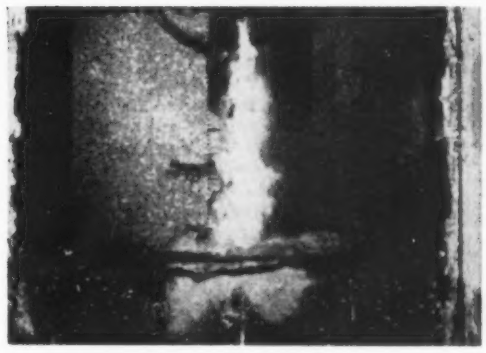
From these observations regarding the interchangeability of the phosphorus and carbon reactions, it can be concluded, with a good degree of probability, that when the lance is close to the bath surface and there is intensive iron spray, carbon removal proceeds, as in the basic Bessemer converter, mainly by way of carbon monoxide, as is well known from the normal LD process. When the lance is at some considerable distance from the surface of the bath and there is only a slight amount of spraying, the carbon dioxide content of the waste gas will, however, increase during carbon elimination. In this case, oxygen utilization is poorer in view of the lesser surface which is presented.

The use of oxygen with, or instead of, the air blast of the normal basic Bessemer process already produces a thermal gain. A further thermal gain can be obtained in the converter by burning carbon to form carbon dioxide instead of carbon monoxide. It is clear that such heat recovery substantially affects the economics of the process.

Since, however, a single lance position for advancing dephosphorization and for attaining a higher degree of



8 *IRSID lance; pure air: no penetration of the jet*



9 *IRSID lance; air and sprayed water: penetration of the jet*

after-combustion of CO in the converter inevitably means that it is necessary to operate with inhibited carbon elimination, there is an increasing danger of eruptions such as are associated with the delayed boil and enrichment of the slag with ferrous oxide, together with temporary supersaturation with oxygen of the still carbon-rich metal. At the same time there is vigorous foaming of the slag. Under such conditions, not only the economics but also the operational safety of the process suffers.

When several lances are used,[8] part of them being so adjusted that, with a weak jet, carbon elimination no longer proceeds beneath them but dephosphorization occurs, and the remaining lances are adjusted for a sharp jet to produce carbon elimination, it is possible to effect a reliable measurement of carbon elimination and to control blowing technique and reactions.

The reason these trials are again referred to is not that they might perhaps show for the first time a technically possible process for converting high-phosphorus pig iron by oxygen blowing but because they demonstrated that these concepts associated with the delayed boil of carbon elimination are correct even if occurring side by side, and thus provided the fundamental operating instructions which have to be applied in whatever guise the problem of the oxygen treatment of high-phosphorus pig iron may appear. The rule is: the bare metal surface which is available for carbon elimination must be precisely controlled, as must also the proportion of oxygen which is available for dephosphorization via the slag.

It is clear that an addition of ore, i.e. of 'slag oxygen' directly facilitates dephosphorization[18] and permits dephosphorization to proceed until the carbon has taken possession of this oxygen. It is already known from the basic Bessemer process, that higher additions of ore made at the beginning, delays dephosphorization to some extent.[19] An addition of calcium fluoride[20] has a similar effect and acts not only as a flux but also, by virtue of its property as a salt, increases the activity of the ferrous oxide.[21]

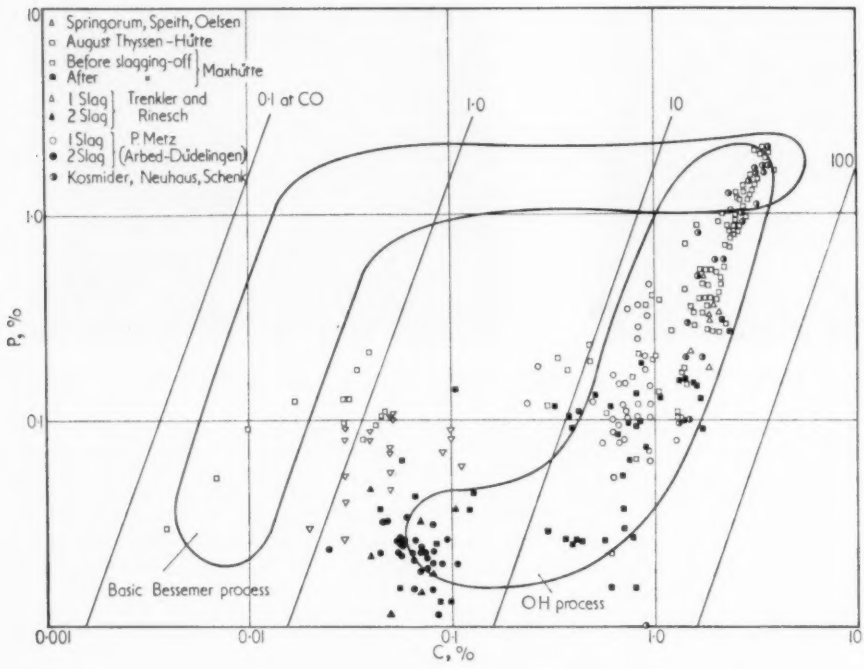
Considering that even in the bottom-blown converter with its excellent bath movement, dephosphorization is improved by the addition of crushed lime, it is to be expected that with top-blowing, where there is still greater danger of moving further away from equilibrium, the addition of powdered lime to the oxygen jet will likewise promote the necessary advancement of dephosphorization.[22, 23]

In addition to this, however, there is certainly a special effect associated with the addition of solid particles to the blast for the carbon elimination reaction. Since the solid particles in the free jet will not follow to any great extent the turbulent movement of the gas molecules, the centre of the spreading jet will remain rich in solid bodies. If the distance between the lance and the bath surface is such that a pure oxygen jet penetrates the metal bath to only a slight extent so that there would be scarcely any spraying of metal, good dephosphorization is certainly possible but only poor carbon elimination. The danger of carbon elimination completely ceasing at times so that repeated eruption-like ejections occur, will increase. With the addition of powdered lime to the oxygen, however, the impulse-richer core of the jet will still have such a high 'penetration power' that the lime particles will penetrate the iron bath. There they act as nucleation or boiling centres and prevent the cessation of the carbon elimination reaction. The outer regions of the jet which are poorer in impulses will then dephosphorize while the core of the jet can compel a continuous carbon elimination according to the locally available surface which is laid bare and the oxygen supply. A jet rich in solid particles penetrates much deeper than a mere gas jet (Figs.8 and 9).[24] Thus, this process offers at once a sure means of promoting dephosphorization without risking the danger of a temporary complete suppression of carbon elimination.

It is interesting, that in all processes, and here the rotor processes should be specially mentioned, in which it is possible to advance dephosphorization, a type of reaction between carbon elimination and dephosphorization sets in very similar to that which is known with the refining of basic Bessemer pig iron in the OH furnace (Fig.10).[25] In the processes under consideration this simultaneous evolution of carbon elimination and dephosphorization is completed only at higher phosphorus contents for heats in which carbon elimination is predominant and at lower phosphorus contents for those heats in which carbon elimination is less predominant.

Possibilities of the rotor processes

The rotor processes,[26, 27] insofar as the vessels can rotate rapidly enough, are not dependent on carbon elimination as a 'bath engine' for adjusting concentrations between slag and metal. They can, therefore, supply oxygen to the bath only by way of the slag and



10 *Development of dephosphorization with various processes of top-blowing refining of basic Bessemer pig iron*

support an oxidizing atmosphere within the converter, as in the OH furnace. The rotor processes can also oxidize without the presence of carbon, e.g. dephosphorize. The oxygen gradients between metal and slag can be varied according to the rotation speed during refining and it is obvious that, with increasing rotation speed, the metallic surface area which is laid bare is increased. Carbon elimination can then be allowed to proceed preferentially, even in advance of dephosphorization.

Even if, as seems likely, it becomes possible to conduct these processes either with the metallurgical characteristics of the bottom-blown basic Bessemer process or with those of the OH process using the slag as refining agent, it is desirable to have a practice which combines the features of both processes. The oxidation gradients between metal and slag, as in the bottom-blown converter, should be as small as possible. It is, however, necessary that a notable delay in the carbon elimination boil shall be maintained and that there shall be a predominantly oxidizing atmosphere with the combustion of carbon to carbon dioxide in the furnace chamber. A prerequisite to this requirement is a pronounced non-equilibrium between gas phase and slag phase. At the same time, the period of the blow must be short with the pronounced oxygen reaction. This means that the movement of the vessel, using the lining as a 'friction gear' is transmitted to the bath in such a manner that metal and slag are quickly brought in balance with each other without the appearance of a more extensive bare metal surface than is required for the desired carbon elimination. The Kaldo rotor seems to fulfil these requirements.

In the oxygen top-blowing process (LD process) such a requirement can never be posed or fulfilled because only when carbon elimination is maintained under at least part of the jet can adequate bath movement be ensured, and because the sprayed iron within the converter prevents the complete after-combustion of carbon monoxide to carbon dioxide.

Since both the rotor and blowing processes are accepted today as operationally sound and capable of producing steel of the same quality, a choice of process will depend on economics, yield, vessel life, blowing period, output, and many other items.

The rotor processes use a more economic charge and the best possible heat utilization in the converter. It is, however, to be feared that these advantages will be offset by reduced converter life and lower output due to a longer blowing period.

The oxygen top-blowing processes, on the other hand, have to compensate for their narrower metallurgical limits by lower lining consumption, higher output, and lower capital costs and depreciation.

CONCLUSIONS

1. Equilibria are approached but not attained in the basic Besssmer converter. Carbon elimination proceeds in an uninhibited manner.

2. In the OH furnace, the gas phase (CO_2 content) and slag, the slag and metal, and the carbon and oxygen in the metal are in non-equilibrium with each other. Carbon elimination is inhibited. The carbon elimination reaction is responsible for bath movement.

3. In the oxygen top-blowing process, the progress of carbon elimination, i.e. the extent of the carbon elimination inhibition, and thereby the sequence of carbon elimination and dephosphorization, depend on the intensity of the blast. A 'hard' jet causes carbon elimination while a 'soft jet' dephosphorizes. An addition of powdered lime to the jet has a dynamic effect apart from the metallurgical effect. It helps to control carbon elimination with the more deeply

penetrating jet, and carbon elimination is the main element controlling bath movement.

4. The rotor processes tend to support non-equilibrium between the gas phase (CO_2 content) and the slag but they tend to cause an approach to equilibrium between slag and metal when carbon elimination is inhibited. This seems to succeed in the Kaldo rotor.

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The use of models for investigations of oxygen steelmaking processes

B. S. Holmes and M. W. Thring

INTRODUCTION

THE ADVENT of tonnage oxygen, now increasingly available, has made its use in the steelmaking industry economic. The advantage of its use is likely to be felt even more so in the future as the price of fuel seems likely to rise. Oxygen is used in three ways at the moment, to enrich combustion air, direct injection into the melt, and for pretreatment, i.e. desiliconization. The first is only important under special circumstances, for example if the regenerators work badly and preheat is not available. The snag is that the extra heat is produced above the bath, therefore the roof is exposed to excessive temperatures. The second system has the advantage that the heat is produced right in the melt where it is required, also the stirring action of the jet or jets helps with the process to a considerable degree. The third application is only used where excessive silicon content of the raw material is a trouble; this stage could be incorporated into normal refining if the vessel were suitable, i.e. to hold the foam produced and maybe to get an intermediate slag off.

Models are used to investigate these processes both from a design point of view and for development of existing plant. Models of existing plant are built to exact scale; the processes going on are first simulated exactly, then the models can be modified to make the present process either better, or more economic. They are used by the designer, who builds a model of his design to see how the model works before the plant is even built. It is imperative for design work that similarity exists or the model work is useless. In the first type of work trends can be followed and conclusions arrived at without true similarity really existing.

The action of the oxygen jet is partly physical and partly chemical, as was shown by Warren[1] in the USA as long ago as 1948. Oxygen, air, and nitrogen were separately injected into the bath of a 220-ton OH furnace. Over the range C=1·2–0·5% the normal rate of carbon elimination was 0·5 points/ton min. This was accelerated to 1·2 with oxygen, to 1·0 with air, and to

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SYNOPSIS

The use of models is discussed and the necessity for similarity emphasized. The action of the oxygen jet is partly chemical and partly physical, but whether the physical action responsible for refining, is stirring or splashing is not known. There are optimum positions for the lance or lances. Two theories of the refining mechanism are stated and their significance to model work discussed.

The use of models in the past is reviewed and the evidence put forward for the use of the modified Froude number as a criterion of similarity in this work. Model work done on the top-blown oxygen converter is described, although no data on similarity in this work are available.

There follows the statement of three theories for the mechanism of the splashing, which always occurs at high blowing rates. Suggestions are made as to how the modified Froude number might be amended to account for any excess splashing taking place owing to chemical action.

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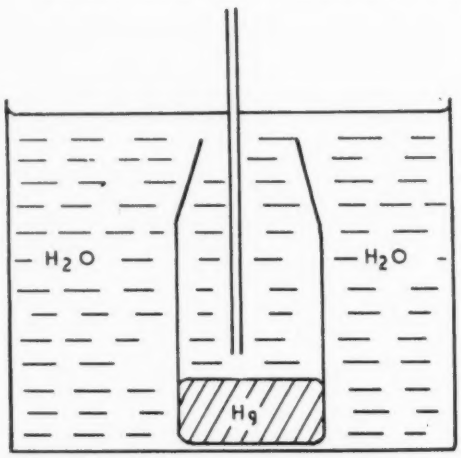
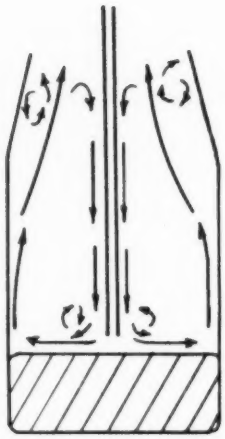


1 *Model for simulating gases*



2 *Circulation in model with weak blowing*

0·7 with nitrogen. This shows that the stirring action or the splashing action of the jet are important. As the level of carbon drops, nitrogen pick-up becomes important, and the trend in the Oxy Thomas process is now to start the blow with oxygen-enriched air and to change over to steam oxygen about half-way through the decarburizing period when nitrogen pick-up begins to be marked; a higher oxygen rate could be used for the last few minutes. A system like this could be applied to the OH furnace. Whether it would be advantageous or not would only be a matter of economics.

Parker and Schane[2] in a report on the use of oxygen at the United States Steel Corporation state that trials have been made with lances through the back walls, furnace ends, roof corners, and roof centre. These trials showed that the best position for the lance is the roof centre; this agrees with reports received on the use of oxygen in the UK. The authors therefore will use a lance in this position in any model work undertaken. This applies of course with one lance, if more than one were used then they would be placed either on the centre line or symmetrically about the centre line.

It is reported from the USA that a shallow bath furnace will not accommodate steep angles and high velocities owing to bottom erosion; no confirmation has been found of this in the UK.

The rate of oxygen flow can be determined by economics: at low flows, heat action is irregular and little benefit is obtained, at high flows furnace life becomes critical owing to a possibility of excess temperature, also control is difficult. The efficiency of oxygen usage from all reports is very high and a given amount of oxygen whether supplied through a single lance or multiple lances will do the same work. One lance is easier to control but more lances may be needed to keep things within the optimum conditions. Model work will be very useful in finding optimum conditions, i.e. top and bottom limits of oxygen flow rate and also how many lances will give most economic usage.

Two theories[3,4] have been put forward to explain the refining mechanism; model work is unlikely to shed any light on which of these is true but conversely it would help the model work to know which is true.

Focus point theory This is due to Kosmider and states that the vast majority of the oxygen is absorbed at the point of impingement. The requirement of this is that the jet should penetrate as deeply as possible to use the oxygen most efficiently and to stir the bath.

The second theory This is due to Rellermeyer and says there will be some absorption at the focus point but the major portion of the action is above the bath, the iron droplets being oxidized and dropping back all over the bath, the reaction then continuing as with millscale.

The important thing from a model point of view is that the first theory requires deep penetration with little splashing. The second theory only requires penetration of the slag as far as the interface plus a lot of splashing.

PAST USE OF MODELS

Models are now being used regularly by steel companies all over the world for exploration of OH furnaces and other steelmaking units. The most relevant work to the present problem is that done by Newby,[5] on the side-blown converter, and by Hasimoto,[6] on gas flow in the top-blown oxygen converter.

Newby was the first worker to make use of the modified Froude number:

$$\frac{\rho g}{\rho l} : \frac{v^2}{lg}$$

ρg=gas density, ρl=liquid density, v^2=exit velocity of jet, l=linear dimension (diameter of jet), g=acceleration due to gravity.

The Froude number comes in because the liquid disturbance depends on the ratio between the inertial force of the jet disturbing the surface and the force of gravity tending to flatten it out. For full similarity the ratio of gas density to liquid density should be the same in the model as in the full-scale plant. Since it is the inertial force of the gas which counts rather than that of the liquid, it was considered that sufficient criterion for similarity was the ratio of inertial force in the gas to gravity force in the liquid, hence equality of modified Froude number in model and original. Newby tested this theory by making two models with an equal modified Froude number, one using mercury

as liquid and the other using water. The disturbances were found to be the same. It was also shown that the disturbances were not the same when the gas Froude number used in the mercury model was used in the water model. Newby then made a model of the disturbed surface with plasticine, replacing the air in the model with water. The water was operated with Reynolds similarity. He found that the blast shot across the surface of the bath and up the far side of the converter and that the heavy erosion just above the tuyeres was due to a downflow of recirculated gases being entrained by the jet.

Work was done more recently by Hasimoto. This was on the top-blown oxygen converter. He used a model as shown (Fig.1) with water to simulate gases and with mercury as the liquid. His paper states all dimensions in terms of vessel diameter, thus some criterion of similarity must be assumed. The model was made of glass, the lower part of the vessel being filled with mercury. The entire model was placed in a glass container filled with water. Injection was accomplished by using a glass pipe which blew in water mixed with tracers. The model was illuminated by a slit of light in the usual way for observation and photography.

Hasimoto found that the intensity of injection changed the flow characteristics profoundly. With weak blowing the gases crept along the bath surface and up the walls, the main body of the gases left from the centre of the converter mouth but some recirculated down the injector and formed a doughnut-shaped ring around the jet. Another portion turned towards the walls and formed a collar around the mouth (Fig.2).

As the injection is intensified the doughnut ring disappears, the collar becomes smaller, and the ascending flow has a considerably wider pattern. As the injection is increased still further (i.e. to the point where splashing begins) the doughnut ring reappears.

The effect of raising the jet was found in general to be the same as weakening the injection, except that the jet struck a wider area and the width of the ascending flow around the injector increased. The doughnut-shaped ring developed well.

FUTURE USE OF MODELS

Three theories have been put forward describing the mechanism of splashing:

(i) the first is that splashing is completely physical and consequently the amount of splashing will depend on the jet momentum

(ii) the second is that the oxygen is absorbed into the steel and carbon monoxide is then formed explosively causing the splash

(iii) the third is a compromise and claims that the splashing is partly physical and partly chemical, the oxygen combining with carbon on the surface.

The first theory has been enlarged upon by Hammer[3] who claims that the jet impinges on the bath surface creating a fairly deep impression. Part of the oxygen is absorbed by the bath and the remainder, i.e. the major portion, is diverted upward. A jet reaction is created between the jet entering the bath from above and the jet ring directed obliquely upward. The upward jet is accelerated. This secondary upward jet causes friction and a suction effect at the oblique wall of the impression, droplets become detached and are entrained with the jet.

With the other two theories the jet momentum will only be important as far as penetration of the slag is concerned. There will in fact be more splashing than would be expected from jet momentum considerations.

If the first theory is true then it will be possible to scale on the modified Froude number as shown by Newby and Thring.[5] If there is more splashing than is provided by the modified Froude number then it may be possible just to multiply by a constant for all cases.

If no correlation is found with the Froude number then it will still be possible to continue with model work on an empirical basis. This has already been done to a certain extent in determining the best angle of impingement for the jet. This can only be done on a cause and effect basis, therefore the effects on furnace life and performance must be thoroughly investigated.

The use of two liquids in the model to represent slag and steel presents little difficulty theoretically, provided the ratio of the densities of the two layers is the same as slag to steel. The problem arises practically in making two layers visible so that the droplets of one can be distinguished from the droplets of the other. Determination of the slag/steel density ratio will be hard as the slag density is constantly varying but a good approximation within the expected accuracy of the work should be 1:3.

The effects of the jet in the furnace will be obtained by taking photographs with a water-cooled telescope. With the aid of these photographs it should be possible to decide which of the spraying theories is true and thence to decide on the proper criteria for similarity.

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A model experiment to study the rate of gas evolution from the bath of an LD converter

J. M. van Langen

SYNOPSIS

This paper describes the flow pattern within the bath resulting from the interaction between gas and liquid in a $\frac{1}{26}$-scale model of an LD converter. In the model the bath consists of a sodium bicarbonate solution covered with a 'slag' layer of paraffin oil onto which dry hydrochloric gas is blown. It is shown that the stirring action of the gas jet is very small and that an acid top layer is formed which gradually grows until nearly the whole solution is acid. The last of the basic liquid usually mixes suddenly with the acid, which gives an increased gas evolution. This phenomenon is often encountered in the LD process. An alternative position of the gas jet is suggested which gives a better stirring action of the bath. The similarity criteria of the model are not well established, and therefore the results can only be qualitative.

1908

INTRODUCTION

IN THE COURSE of the LD process there are two periods of increased foaming occurring regularly at the same time after the start of blowing. The foaming phenomenon is a product of the foaming properties of the slag and the rate of gas evolution from the bath. In this paper only the second will be considered, with the help of a model.

DESCRIPTION OF THE MODEL

The model consists of a glass vessel of which the inner shape of the bottom part is a replica on $\frac{1}{26}$ scale of the LD converter in use at IJmuiden. To study the gas evolution it was decided to choose a liquid and a gas which together form another gas as a product. In the LD process $C+O_2 \rightarrow 2\,CO$, at least 90% of the gas product is CO and therefore for every gas molecule of O_2, two molecules are produced. We have not been able to find another simple combination of reactants producing gas in the ratio 2:1. The best we have found is the combination HCl–$NaHCO_3$ producing gas in the ratio 1:1, $NaHCO_3+HCl \rightarrow NaCl+H_2O+CO_2$.

Thus, for the bath liquid a saturated solution of $NaHCO_3$ was chosen with, as indicators, methyl-orange changing from orange to red or brome-thymol-blue changing from purple to yellow. As material for the gas-jet we have chosen dry pure HCl gas supplied from pressure bottles. A 'slag' layer was provided consisting of paraffin oil or kerosene.

The momentum of the gas-jet was chosen such that the dimensions of the hole made in the liquid were similar to those calculated for the LD converter, i.e. the largest depth is about half the total depth of the bath. The width of the hole is determined by the height of the lance above the bath and this is $\frac{1}{26}$ of the actual height in the LD converter. Thus, geometrically, the model is as close as possible to the full-size LD converter.

Differences between model and converter

1. It is probable that the foaming properties of the slag (which are unknown) are not correctly reproduced by paraffin oil.

2. The relation of specific gravity of slag and bath is about 2·5:7·5 for the converter, and 0·8:1·05 for the model. It is not known whether the difference in specific gravity within the bath layers in the course of the blowing process influences mixing. It would seem that there are no large gradients in specific gravity in the converter, as hot metal of about 1350°C has the same specific gravity as steel of 1620°C. In the model the specific gravity varies from 1·07 g/cm³ (20°C) for the original solution, to 1·05 g/cm³ (35°C) for the final product.

3. For each mol of gas blown in the bath 2 mols of gas are produced in the converter and only one in the model.

Owing to these differences one can only hope to obtain some qualitative and perhaps relatively quantitative results from this model.

RESULTS

The main result was the discovery that the stirring of the bath by the gas jet in the usual geometry had little effect, although the blowing depth was relatively great and the splash of liquid from the surface was so severe that many droplets were thrown out of the model (Figs.1*a–c*).

The mechanism of the process appears to be that HCl gas is taken up in the bath on the surface of the

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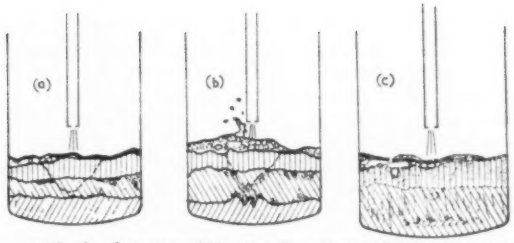
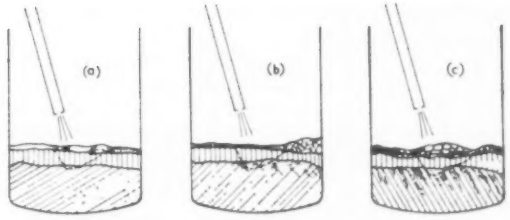


a 1½ min after start of blowing. Two distinct layers are present in the bath
b 2½ min after start of blowing. The acid layer has grown considerably
c 3¼ min after start of blowing. Only a small portion of basic liquid is still present. Increased gas production in the bath

1 *Vertical blowing of* HCl *on* $NaHCO_3$ *with a paraffin 'slag' layer*



a 1½ min after start of blowing. All the liquid is still basic
b 3½ min after start of blowing. The liquid is about neutral. The indicator has its intermediate colour.
c 3¾ min after start of blowing. The liquid has in a very short time completely changed from basic to acid

2 *Radial blowing under 75° to the bath*

blow-hole and that reaction of the acid layer so formed with the $NaHCO_3$ takes place at the interface, producing CO_2 bubbles everywhere along the interface of basic and acid liquid. In this way the acid top layer progresses slowly downwards until at the end of the process the last of the basic liquid suddenly mixes with the acid which gives an increased gas evolution. If after blowing for some time the layer structure of the bath is disturbed in any way, e.g. by stirring, greatly increased gas evolution also takes place which again increases the mixing and thus accelerates itself.

Comparing this behaviour with the LD process the following resemblances appear. If the slag does not foam, the splash of the jet also throws out droplets of iron. This occurs especially in the first minutes of the blow. Afterwards foam is usually formed which chokes the splash and two maxima of foaming are encountered; the first as soon as the foam is formed, and the second near the end of the blow. It appears that the first period depends mainly on slag foaming properties and the second is caused by an increased production of gas as seen in the model.

Because, as has been pointed out, no complete quantitative rules can be applied to the construction of the model, measurements can only show qualitatively what is the effect of varying those factors which can be readily varied in the converter.

The following variables have been tested in the model:

Slag viscosity
A decrease in slag viscosity decreases the tendency of the bath to form layers. In the model, paraffin oil was compared with kerosene.

Thickness of the slag layer
Decreasing the thickness of the slag layer decreases the layer formation. In the model, 150 cm^3 *v.* 100 cm^3 of paraffin oil or kerosene was applied.

Foaming properties
Decreasing the tendency of the slag to foam decreases the layer formation. In the model 5 cm^3 of Teepol were added to the liquid in a few cases.
A shallower bath decreases the tendency to form layers.
A greater jet-momentum of the gas-jet gives an increased stirring action.
A smaller distance between lance and bath gives an increased stirring action.
Position and shape of the nozzle of the gas jet can improve the stirring of the bath.

Stirring

We have tried to increase the stirring of the bath by altering the position of the jet source, and carrying out the following experiments:

1. Blowing with two jets each under an angle of 10° to the vertical and each with half the momentum, so that on the bath two holes were formed, each with a depth of 0·2 × depth of bath. The stirring was worse than with one vertical nozzle with its full momentum producing a blow-hole of 0·45 × depth of bath.

2. Blowing with four jets each under 10° to the vertical and each with ¼ of the momentum, so that on the bath one wide shallow hole was formed. The stirring was bad. The appearance was the same as was found with one nozzle by doubling the height of the nozzle over the bath.

3. Blowing with one jet in the normal setup and the normal jet momentum but with a mixture of HCl and inert gas. The idea was to increase the amount of gas that leaves the hole formed on the bath and to increase the movement in the liquid by the high velocity gas stream that flows along it. The amount of gas leaving the hole can be increased in this manner because less of the primary gas stream is taken up in the bath. This measure did not make any difference to the stirring action of the jet.

4. Changing the angle of the axis of the jet to the surface of the bath. This angle has been varied in steps of 2° from 90° (normal position) to 74°. The horizontal component of the gas velocity so obtained was directed along a radius of the bath. The point where the axis of the jet touches the bath, is the centre of the bath. This is later referred to as 'radial' blowing. The result was that with angles of 80–74° a very good stirring occurred to such an extent that no layers were formed and the reaction took place with a regular gas production (*see* Figs.2*a–c*). This setup has never been tried in practice in the full-size converter, because in the meantime a method was found to lessen foaming by controlling the foaming properties of the slag.

The method was checked in a desiliconizing vessel for which the bath-diameter/depth relation is much more unfavourable and in this case a layer structure was found in the case of vertical blowing and an even distribution in the case of radial blowing under 75°.

5. Blowing under an angle of 75° to the bath surface but tangentially to a circle with radius ¼ and ½ of the radius of the bath surface. Very good stirring was found in both cases but the formation of waves along

the walls of the vessel was considered too severe in the case of the larger circle.

Although the stirring action of the setup is very good, especially in the case of the desiliconizing vessel for which the model indicated better results than with radial blowing under an angle, technical difficulties made a practical trial too costly.

CONCLUSIONS

The experiments described have shown that there is a definite possibility that in reactions taking place between a liquid and a gas which is blown on to the liquid, a layer structure of the reaction products is built up, although the blowing action seems rather severe.

A setup of the gas jet so as to improve its stirring action has been found. For an oxygen steel converter with a bath-diameter/depth relation of 2·3:1, radial blowing under an angle of 80° to the bath surface has been found sufficient. For the desiliconizing vessel with a bath-diameter/depth relation of 1·1:1, tangential blowing under 75° to the bath surface on a radius of one-quarter of the bath radius has given good results on the model.

ACKNOWLEDGMENTS

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The aerodynamics of open-hearth furnace regenerators

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SYNOPSIS

A technique is described for determining the flow distribution in an open-hearth furnace regenerator by means of cold trials. The maldistribution found in conventional regenerators can be expected to lead to lower preheat than is otherwise possible. It is shown that suitably placed baffle walls are capable of giving improved distribution, and the suggestion is made that the location of the bottom fantail flue on the same side of the regenerator as the slag pocket would also lead to better performance. Partially blocked settings might have a better distribution than new ones.

1900

INTRODUCTION

ONE OF THE AIMS of most open-hearth furnace managers is to obtain the maximum possible air preheat from the regenerators at his disposal. A factor which affects the preheat attainable is the degree of uniformity of the flow to the chequers of the air and waste gases. For maximum air preheat, simple calculations will show that both gases and air should be spread evenly over the chequer brickwork. Unfortunately, the normal siting of conventional (i.e. up and down flow of air and waste gases, respectively) regenerators with respect to other units, such as the slag pockets and flues, leads to an aerodynamic system conducive to non-uniform distribution of both air and waste gases.

It has been fairly widely recognized for a long time that such maldistribution is likely to occur in practice, but the obvious difficulties in experimentation with actual working plant formed a bar to progress until the benefits to be obtained by the application of model techniques was recognized by the steel industry, largely through the pioneering efforts of Dr J. H. Chesters.

However, the use of perspex air or water models suffers from certain disadvantages in this connexion. Their construction and use is often both tedious and time consuming.

Mere flow pattern visualization (for example, in the open space above the chequerwork), by the use of suitable tracers and slit illumination, does not necessarily give a good indication of the actual distribution to the chequers themselves. Attempts to assess the distribution quantitatively by means of small pitot tubes are often tedious, difficult, or, in the case of air models operating at low velocity, abortive. It is difficult, in a model, to simulate the effect of dust deposits.

In the work described here, flow distributions have been determined in cold trials of actual regenerators. It is suggested that the technique is one which can usefully supplement or even replace the use of scaled models when existing regenerators (or other systems) are the subject of an investigation. One of its main attractions is the ease and rapidity with which a mock-up of a device for improving distribution (a baffle wall, for example) can be introduced and its effect determined. The work now reported is part of a fairly comprehensive series of investigations in the field of regenerator performance undertaken by members of the Department of Fuel Technology and Chemical Engineering.

Significance of flow distribution

An idea of the order of magnitude of the effect on air preheat of maldistribution of the air and waste gas flow may be obtained from the following crude comparison:

Suppose that a furnace is operating with perfectly uniform air and waste gas distribution to the chequers,

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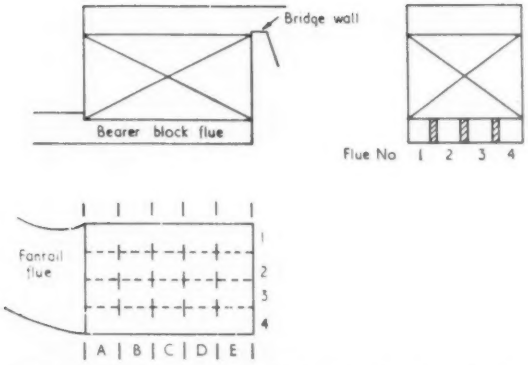
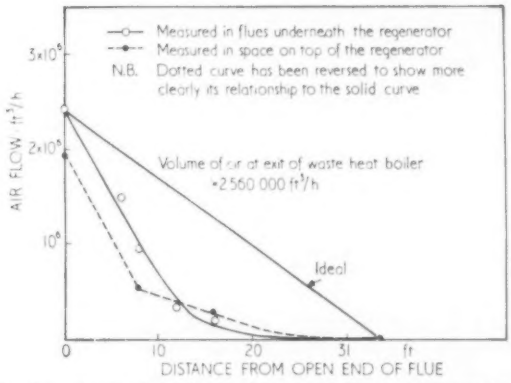


1 *Sketch showing arrangement of regenerator on L furnace, works 1, and illustrating nomenclature*


Measured in flues underneath the regenerator
Measured in space on top of the regenerator
N.B. Dotted curve has been reversed to show more clearly its relationship to the solid curve
3x10⁵
2x10⁵
10⁵
AIR FLOW, ft³/h
Volume of air at exit of waste heat boiler = 2 560 000 ft³/h
Ideal
0
10
20
31
ft
DISTANCE FROM OPEN END OF FLUE

2 *Sum of rate of air flow in bearer arch flues* v. *distance from open end of flue*

and that the air preheat temperature attained is 1000°C. Now assume that the distribution of air and waste gases to four equal areas (in plan) of the chequers is modified as follows:

Waste gases, %	40	30	20	10
Air, %	10	20	30	40

If it is now assumed that the regenerator may be treated as a counterflow recuperator in which the overall heat transfer coefficient is constant, then the average preheat temperature of the air (corresponding to the temperature resulting from the mixing of the above four air streams) is only 811°C.

It is true that the above does not take into account the variation in overall heat transfer coefficient which would result from the variation in velocity in the four sections. However, the correction for this effect would be relatively small.

It should perhaps be stressed that the distributions actually measured suggest that the above assumed figures are by no means unrepresentative of those which occur in practice. Indeed, in several instances, actual recirculation was found to occur. Thus, on downflow, it was not uncommon to find upward recirculation taking place in regions near the bridge wall adjacent to the slag pocket, and, conversely, on upflow, downward recirculation occurred at the opposite end of the regenerator chamber. Comparatively little recirculation is required to impair considerably the performance of a regenerator.

The above comparison serves to indicate the magnitude of the prize to be won if efforts to improve the flow distributions are successful.

SIMILARITY CRITERIA

The similarity criteria which apply to the present investigations are identical to those which apply to the use of models. Indeed, a cold trial of a regenerator may be regarded as an experiment with a full size model. It is not possible to obtain exact similarity, owing to the effects of buoyancy in a normal working regenerator. Nevertheless, it is believed that this effect does not invalidate the conclusions to be drawn from the work. Subsidiary measurements made in a working regenerator, described later, and the paper by Chapman *et al.** seem to support this view.

As in model work of systems of this type, Reynolds' similarity is desirable. This requires that the Reynolds' number in the cold trial should be the same as during normal regenerator operation. The Reynolds' number is given by $4w/d\mu$, where w is the mass rate of flow of air or waste gases, μ is their absolute viscosity, and d is a characteristic dimension of the system. Since d is identical for both normal operation and in the cold trial, the ratio of the flow rate to be used in the latter to that for normal operation is given by the ratio of the viscosities under the two conditions. Thus

$$\frac{w_{\text{cold trial}}}{w_{\text{normal working}}} = \frac{\mu_{\text{cold trail}}}{\mu_{\text{normal working}}}$$

A complication arises here, since during normal operation the temperature, and hence the viscosity, of both air and waste gases changes progressively as they pass through the chequers. The limiting values of the ratio of the mass rates of flow in the cold trial to that for normal operation are, for normal working conditions, as follows:

	Above chequers	*Below chequers*
Downflow		
W. gases thmp. range, about 1600–800°C	1/3½	1/2½
Upflow		
Air temp. range about 200–1200°C	1/3	1/1¼

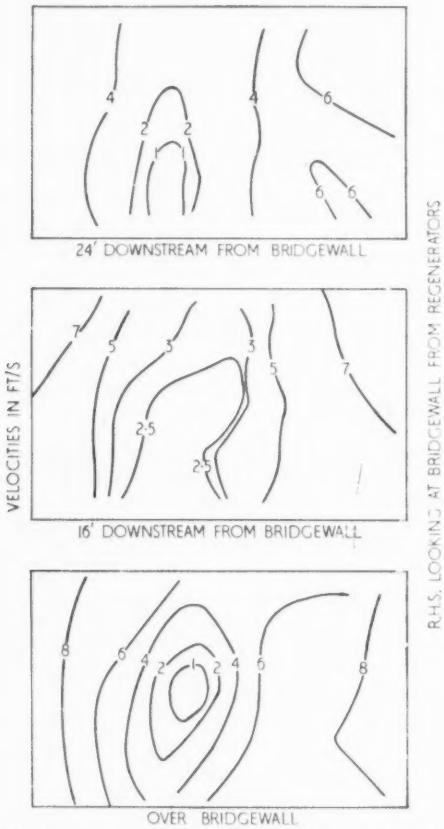
Since in the cold trial the air temperature is relatively constant, it is not possible to arrange for a variable ratio. Accordingly the rate of air flow employed has normally been determined in practice by the entrance requirements (above chequers on downflow and below chequers on upflow), since it seems reasonable to suppose that the entrance conditions will have a greater influence on the distribution than those at the exit. Trials carried out over a range of flow rates on one particular furnace showed that the value of the Reynolds' no. had an almost negligible effect on the distribution in the normal working range.

EXPERIMENTAL PROCEDURE

Up and downflow of cold air were obtained by operation of the FD and ID fans, and suitable manipulation of the furnace dampers. Flow rates were determined at selected stations by carrying out velocity traverses with a Metro–Vickers Velometer.

The precise procedure varied slightly from furnace to furnace, being dependent, among other things, on the number of bearer arch or bearer block flues below

* J. Chapman and W. Montgomery: *JISI*, 1960, **196**, 15–28



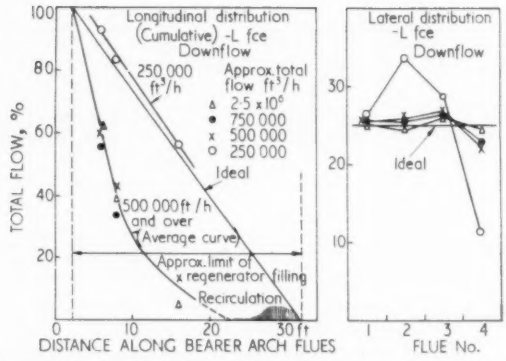
3 *Velocity patterns above chequerwork, L furnace, works 1, at various distances from bridgewall. All refer to downflow of air. Vertical scale is magnified ×4*

the regenerator chequerwork. It is typified by the following, which applied in the case of L furnace at works 1. A rough sketch of the arrangements is shown in Fig.1 which gives the numbering of the bearer flues and the longitudinal division into five arbitrary zones of equal area. Velocity traverses were taken as follows:

(i) in the main flue between the fantail and the reversal valve (34 readings)
(ii) at selected distances along the bearer block flues (28 readings at each point)
(iii) above the chequers, in vertical planes parallel to the bridge wall and at various distances from it (50 readings each).

Traverse (i) gave the total rate of flow to or from the regenerator as a whole. The difference in the volumetric flow rate determined at adjacent stations in a bearer flue (ii) gave the volumetric rate of flow to or from the chequerwork in the intervening zone. By appropriate summation, or differencing, a complete picture of the flow distribution could be obtained. A check on this distribution could be obtained, in the case of the longitudinal distribution, from the measurements made above the chequers (iii).

It might be argued that the presence of the body of the observer in the flues would affect the velocity readings obtained, particularly in the smaller bearer flues. This is undoubtedly true, and considerable care was exercised to ensure that the same relative aspect



4 *Longitudinal and lateral distribution, L furnace, works 1, for downflow, Lateral distribution, refer to those at the open end of the bearer flues*

of the observer's body was maintained throughout, in order to ensure comparative results. It was also found possible to correct readings, where necessary, since at the entrances to the bearer flues, two sets of readings could be taken: one with the body in its normal aspect to the flow and the other with no body impeding the flow. It is amusing to recall that the difference of two such sets of readings indicated a projected body area of the observer of about 6½ ft². A moment's reflection suggests that this is about right, although the technique is not advocated for the determination of this quantity.

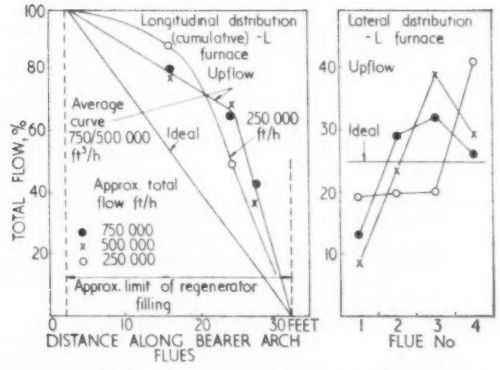
COLD TRIALS AT WORKS 1

Preliminary trial

The results of a preliminary trial of L furnace no.2 regenerator, which contained 520×9 in. square vertical chimney type flues are given in Figs.2 and 3. In this trial it was not possible to reduce the total downward flow of air below about $2{\cdot}5\times10^6$ ft³/h, which is about twice the normal rate of waste gas flow (NTP). However, this fact facilitated later appreciation of the effect of overall rate of flow on the distribution.

In Fig.2 the solid curve represents the sum of the flow rates in the four bearer arch flues at varying distances from the open end thereof (*see* Fig.1). Thus at 0 ft the air flow from all four flues was $2{\cdot}4\times10^6$ ft³/h. As one progresses along the flues the sum of the four rates diminishes. If the distribution were ideal the straight line illustrated in Fig.2 would be obtained. It will be seen that in fact the distribution was far from ideal, that half of the filling nearest the bridge wall being almost starved of air. When the measurements were taken it was possible to observe recirculation in the flues nearest the bridge wall by testing with the smoke from a cigarette.

The distribution of the chequers can also be obtained by consideration of the diminution of the rate of forward air flow over the chequers as one moves away from the bridge wall. The variation of calculated total flow in the bearer flues, based on measurements taken above the chequers is shown dotted in Fig.2. In view of the turbulent and gusty nature of the flow at some points in the system the agreement is considered good, as also is that with the check value of the total rate of flow determined at the



5 *Longitudinal and lateral distribution, L furnace, works 1, for upflow. Lateral distributions refer to those at the open end of the bearer flues*

waste heat boiler. Such discrepancies as exist might be the combined result of air infiltration and recirculation within the setting. However, since the measurements taken in the bearer arch flues seemed the more reliable it was decided to base future measurements of distribution on these.

Velocity distribution in space over chequers

Velocity distributions over the bridge wall and at 16 ft and 8 ft from the reversing valve end (i.e. 16 ft and 24 ft from the bridge wall) are shown in Fig.3. The general pattern is of relatively high velocities near the side walls with minimum values somewhat offset from the central line. At times, in the latter region reverse flow was observed for short periods. It is thought that the pattern observed was formed owing to a rotational motion imparted to the air in passing through the downtake and slag pocket.

Effect of total rate of air throughput

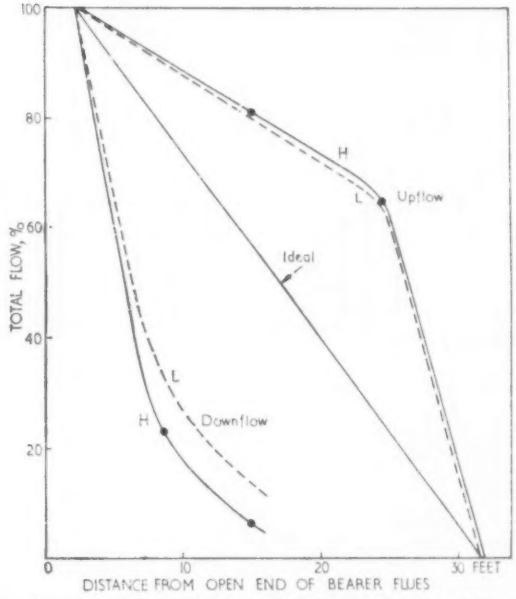
As mentioned earlier, it is not possible to obtain Reynolds' similarity at all points in the regenerator system simultaneously, and for this reason it was decided to carry out tests on L furnace at different rates of flow. The results are shown in Figs.4 (downflow) and 5 (upflow). The upward and downward rates anticipated under normal working conditions had been stated to be of the order of 10^6 ft^3/h.

Downflow

Figure 4 shows that at the higher total rates of flow employed the influence of total flow rate on the distribution was small in the case of downflow but at the lowest rate of flow (250000 ft^3/h) the longitudinal distribution was improved whereas the lateral or transverse distribution became worse. This was probably due to a more streamline condition of flow in the furnace downtake and slag pocket. In general the transverse distribution was excellent but the longitudinal distribution extremely poor.

Upflow

In the case of upflow (Fig.5) both the lateral and longitudinal distributions were bad and the influence of a lower flow rate was not as marked within the range covered. The poor lateral distribution may be ascribed to the effect of the bend in the main flue between the reversing valves and the fantail (*see* Fig.1)



6 *Comparison of longitudinal flow distributions for chimney-type flues and basket-weave chequerwork*

Effect of type of filling

In the case of L furnace (discussed above) the setting consisted of 9 in.×9 in. chimney flues on 12 in. centres. A test was also carried out on H furnace which was of the basket weave type. The results for longitudinal distribution are shown in Fig.6. It will be seen that, as might have been anticipated, the performance in this respect of the basket weave filling is slightly worse than the chimney type.

Combination of downflow and upflow

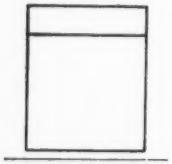
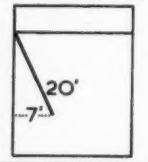
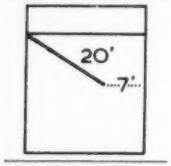
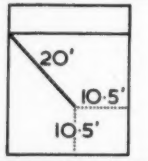
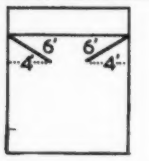
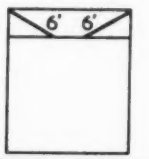
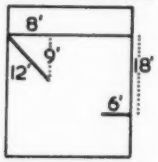
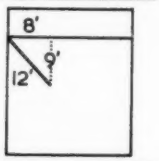
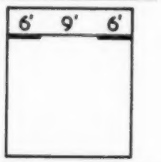
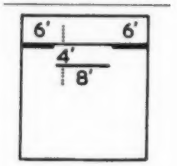
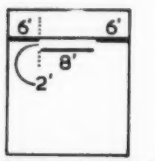
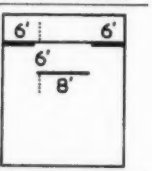
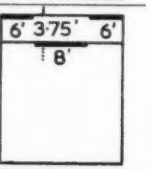
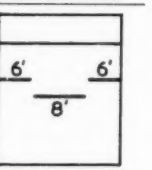
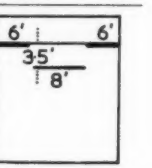
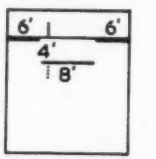
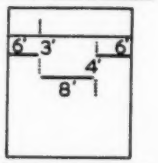
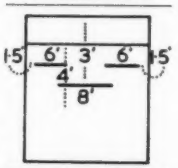
The cumulative longitudinal flows shown in Figs.4 and 5 may be used to assess the percentage of the total flow supplying any arbitrarily chosen strip (in plan) of the regenerator setting. The values for the case of five strips of equal width (A, B, C, D, and E, Fig.1) are as follows:

Strip	Total flow, % Downflow	Upflow
E	60	9
D	25	10
C	11	9
B	4	22
A	0	50

This table serves to emphasize the marked lack of uniformity of flow. However, the situation is made worse by the fact that the regions of high upflow do not correspond with those of high downflow. If the data of the above table are combined with the average lateral distributions (high flow rates) shown in Figs.4 and 5, it is possible to estimate the partition of the total flow to the 20 equal areas indicated in Fig.1. This has been done in Table I. It will be seen that the percentage of the total flow to almost every one of the 20 equal areas is very different from the optimum of 5%.

Upflow/downflow ratios

Table I also gives for these areas the ratio of percent upflow to percent downflow (or vice versa, to give in

Wall	Arrangement	Main flue flow, ft³/h	Total flow at 16 ft, %
1		533000	11·8
2		469000	27·6
3		469000	39·1
4		469000	31·0
5		474000	20·7
6		469000	20·7
7		435000	27·6
8		482000	23·7
9		469000	24·2
10		450000	47·0
11		450000	36·5
12		450000	38·6
13		450000	18·4
14		435000	44·6
15		404000	35·6
16		405000	45·6
17		485000	50·5
18		485000	49·5
19	AS No. 18 BUT WITH WALL HEIGHT REDUCED TO 3·75'	485000	38·0
20		518000	14·3

7 *Effect of baffle walls on air distribution, downflow*

every case a figure greater than unity). The significance of this ratio is as follows. Ideally, with uniform flow distributions, the velocity everywhere is the same and the flow ratio is always one. If this ideal is not attainable, the next best system is one in which although the flows are not uniform, the regions of high and low upflow correspond respectively with the regions of high and low downflow so as to preserve their ratio (on a percentage basis) at unity. The extent to which this ratio departs from unity is a measure, albeit crude, of the extent to which the region concerned will contribute to the less than optimum performance of the regenerator in practice.

Effect of baffle walls on distribution

It would seem that maldistributions of the type discussed above might be improved by the provision of suitably placed baffle walls. Thus, in the case of upflow, the poor transverse distribution is undoubtedly caused by the flow tending to keep to the outside of the bend prior to the fantail (*see* Fig.1), and the situation could be improved by the provision of suitably angled and appropriately long flow dividing walls. It was thought that baffle walls placed above the chequers might also improve the distribution on downflow, but the optimum arrangement of baffle was not immediately apparent. Accordingly, some 19 different arrangements were tried on a basis of trial and error.

Light partitions were constructed from insulation board on a light timber framework, and, in all but one case, their height was equal to the distance between the top of the chequers and the roof of the regenerators. The relative effectiveness of the different arrangements was assessed by a series of flow measurements, taken about half-way along the regenerator setting. (Actually at a point 16 ft from the open end of the bearer arch flues.) The total flow given by traverses in these four positions was expressed as a percentage of the total flow in the main outlet flue measured at a position just beyond the fantail. If a uniform distribution in fact existed, then the percentage of the total flow at this position should be 50%.

The results are shown in Fig.7. The following points are apparent:

(i) all the partitions gave improved distribution over the existing regenerator (shown as partition no.1)

(ii) partitions 2, 3, and 4 form a series in which a 20 ft long partition was placed on the chequers at varying angles to the bridgewall. It is seen that the waste gas distribution is progressively improved as the angle is decreased over the range considered

(iii) partitions 5 and 6 showed comparatively little improvement over the existing regenerator

(iv) partitions 7 and 8 give an indication of the effect of an additional partition, perpendicular to the sidewall, superimposed on a partition of the 2, 3, and 4 type

(v) partitions 2 to 8 are what may be termed the 'Venturi' type, since they offer a gradual reduction in cross-section available for flow; partitions 9 to 18 are of the 'Orifice' type, partitions 10 to 18 are all variations on the arrangement of two 6 ft partitions and one 8 ft partition

TABLE I Partition of flow to 20 equal areas (optimum, 5% to each area)

Flue no. or strip		1	2	3	4
E	Downflow, %	15	15	15	15
	Upflow, %	0·9	2·25	3·15	2·7
	Ratio*	17·0	6·65	4·75	5·55
D	Downflow, %	6·25	6·25	6·25	6·25
	Upflow, %	1·0	2·5	3·5	3·0
	Ratio*	6·25	2·5	1·8	2·1
C	Downflow, %	2·25	2·25	2·25	2·25
	Upflow, %	0·9	2·25	3·15	2·7
	Ratio*	2·5	1·0	1·4	1·2
B	Downflow, %	1·0	1·0	1·0	1·0
	Upflow, %	2·2	5·5	7·7	6·6
	Ratio*	2·2	5·5	7·7	6·6
A	Downflow, %	Negligible	Negligible	Negligible	Negligible
	Upflow, %	5·0	12·5	17·5	15·0
	Ratio*	∞	∞	∞	∞

* Optimum value unity.

(vi) the addition of a third partition in no.10 compared with no.9 is most marked

(vii) the effect of the perpendicular distance between the third partition and the other two is brought out in arrangements 10, 11, 12, and 15. The optimum distance appears to be about 4 ft

(viii) moving the three partitions array bodily on to the bridge wall considerably reduced its effectiveness, as shown in arrangement 13

(ix) arrangements 14, 16, and 17 show the effect of moving the array bodily along the top of the chequers. The optimum distance between the bridge wall and nearer walls appears to be about 3 ft. It will be noted that partition 16 is a repeat of partition 10

(x) comparing 17 and 18, it seemed that moving the 6 ft walls in a direction, perpendicularly inwards from the sidewalls, has little effect

(xi) reducing the height of the partitions diminishes their effectiveness, as shown in arrangements 18 and 19

(xii) blocking some of the chimney flues in the absence of walls showed a slight improvement over the standard regenerator. This improved distribution is at the expense of regenerator capacity

(xiii) the best arrangement tried is shown in arrangement 17.

Some of the results enable the physical effects of the partitions on the gas flow to be explained. It would seem that they cause downflow to take place both upstream and downstream from the partition (*see* arrangements 13, 16, and 17). The former is due to the presence of an obstruction to forward flow; the latter is brought about by the presence of a 'shadow area' of low horizontal momentum in the airstream behind the partition.

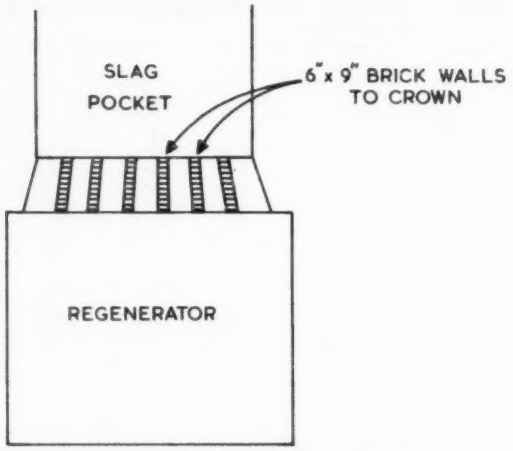
COLD TRIALS AT WORKS 2

The technique used was basically the same as that employed at works 1. Four trials were run as follows:

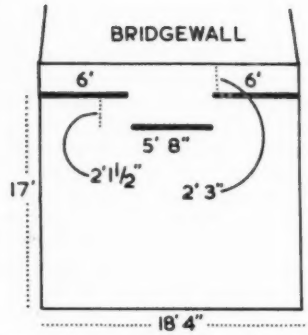
(i) *D furnace* clean regenerator, normal

(ii) *P furnace* clean,* brick walls, as indicated in

* These walls had been built in connexion with another related but independent programme but the opportunity was taken of testing their effect on the cold flow pattern.



8 *Arrangement of brick walls on bridge wall of P furnace*



9 *Arrangement of dummy (hardboard) walls on top of S furnace chequers*

Fig.8, built over bridgewall with the object of 'straightening' the flow

(iii) *S furnace* clean, dummy walls of timber and hardboard were placed over the chequers as shown in Fig.9

(iv) *D furnace* Rotherham end, dirty, that is at the end of a campaign, before demolition and rebuilding of the chequers.

In the case of D furnace, dirty, the furnace above stage level had been demolished, so that the air used in the trial entered and left the system through the open uptake. It should be noted that the regenerators in works 2 were provided with nine bearer-arch flues and had semicircular arch roofs instead of a suspended crown. Nevertheless it was still possible to assess roughly the distribution to the arbitrarily chosen 20 equal areas indicated in Fig.10, by apportioning the flow in those flues which served more than one area.

Trials 1–3 (D (clean), P, and S)

Recirculation

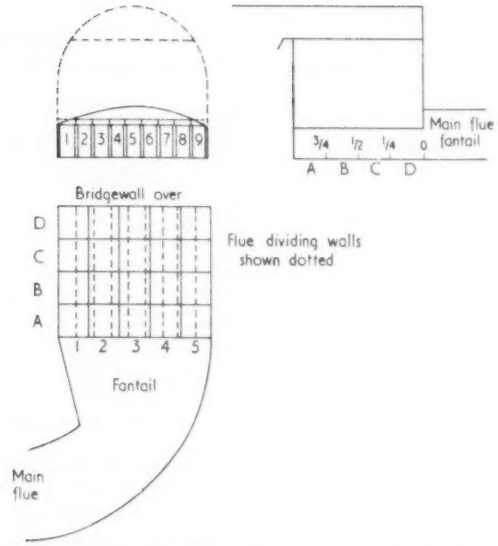
The total rates of flow, as measured at 36 stations in the bearer block flues are given in Table II. It is apparent that on downflow there was considerable reverse flow (recirculation) in the case of D furnace, the whole of the first quarter of the chequerwork adjacent to the bridge wall being involved. It would also appear that the walls, particularly the dummy walls used on S furnace, reduce or eliminate recirculation. In fact, some recirculation was observed (using cigarette smoke as a tracer) in the case of P furnace in the first couple of feet or so from the bridge walls, while in the case of S furnace recirculation was almost entirely eliminated.

In the upflow trials gross recirculation was absent

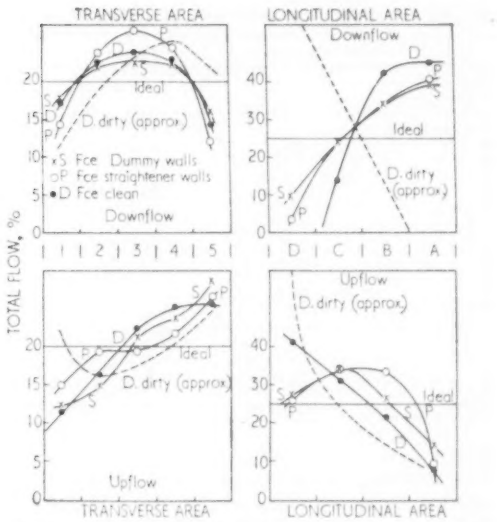
TABLE II Summary of results, trials 1–3

Rates of flow at measuring point, ft³/h Flue no.	1	2	3	4	5	6	7	8	9	Total
Downflow										
(1)	D furnace, clean									
¾*	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative
½	Negative	10600	7600	9600	4400	4700	3700	3900	Negative	44500
¼	6000	25500	24400	29600	28700	22400	19000	17400	6700	180800
0	10600	41800	38100	47500	44000	48000	40200	36500	19300	326000
(2)	P furnace, 'straightener' walls (Fig.1)									
¾	†	4400	†	2600	4700	3000	†	†	†	14700
½	5800	15300	12500	19900	22200	11800	17700	10400	5100	120700
¼	8500	33200	34500	42800	50100	32200	34000	25200	10500	271000
0	19600	50200	58300	68300	64300	61100	64700	46400	13000	445900
(3)	S furnace, dummy walls over chequers (Fig.2)									
¾	2500	1600	3100	3500	4500	3600	3500	4400	5000	31700
½	8700	13100	14800	11800	21000	17300	14100	16400	7000	124200
¼	16400	25000	32600	25500	33000	31000	32100	27800	12100	235500
0	31400	41100	51700	46000	50100	49200	50000	43200	22600	385300
Upflow										
(1)	D furnace, clean									
¾	17000	15400	18100	22500	21200	22500	22100	22800	24000	185600
½	19200	30000	30100	36300	40000	42900	42300	41800	42500	325100
¼	22000	30900	34900	44000	53100	53800	57200	60000	65000	420900
0	12800	34800	37200	49000	60200	61800	65000	70600	61000	452400
(2)	P furnace, 'straightener' walls (Fig.1)									
¾	15900	11400	6900	9500	17300	16700	8700	22900	28400	137700
½	31400	34500	30200	33600	34600	25900	32800	34500	62400	319900
¼	43500	50100	43400	52500	54500	51000	58500	73000	72500	499000
0	38300	49200	56100	62500	57700	54700	70700	92500	62500	544200
(3)	S furnace, dummy walls over chequers									
¾	7600	2600	3900	9200	25500	17300	22500	20200	25100	133900
½	23300	15300	26600	26300	46000	41400	40800	44500	45500	303700
¼	30500	35000	29800	39900	59000	58100	58800	60100	64000	435200
0	36400	28000	39700	51800	64000	64000	71000	73200	76800	504900

* The figures in this column are the fractions of the total distance along the bearer block flues, measured from the open end (*see* Fig.3).
† Flow small or possibly slight reverse flow.



10 *Sketch of regenerator arrangement at works 2, and arbitrary division into 20 equal areas*



11 *Transverse and longitudinal flow distribution in regenerators at works 2*

and is revealed by the figures in Table II, only in flues 1 and 9 for the D and P furnace trials*, and in flue 2 for S furnace. Again, however, some recirculation was observed here, or course, in parts of that quarter of the regenerator remote from the bridge wall. It is not immediately apparent why the dummy walls used in the S furnace trial should reduce the recirculation on upflow. A factor which may influence recirculation on upflow is the presence of small openings from the fantail flues into the chequerwork situated above the bearer blocks.

* It is thought that flues 1 and 9 are more subject to recirculation on upflow because the fantail flue arch partially obscures these outermost bearer block flues.

TABLE III Calculated flow distribution to 20 equal areas. Total flow %, trials 1–3

Area reference (*see* Fig.4)	1	2	3	4	5	Total ideal = 25%
Downflow						
(1) D furnace, clean. Total flow 326 000 ft³/h						
D	Negative	Negative	Negative	Negative	Negative	Negative
C	(3·4)	(4·5)	(2·6)	(2·2)	(0·9)	(13·6)
B	(7·1)	9·7	11·4	8·4	(5·2)	(41·8)
A	6·5	8·3	9·7	11·9	8·2	44·6
Total (ideal = 20%)	(17·0)	(22·5)	(23·7)	(22·5)	(14·3)	(100·0)
(2) P furnace, 'straightener' walls (Fig.1). Total flow 445 900 ft³/h						
D	(0·8)	(0·5)	1·5	(0·4)	(0)	(3·2)
C	(3·4)	(5·4)	6·3	(5·5)	(3·2)	(23·8)
B	4·1	8·4	10·2	6·9	4·1	33·7
A	5·8	9·2	8·1	11·6	4·6	39·3
Total (ideal = 20%)	(14·1)	(23·5)	26·5	(24·4)	(11·9)	(100·0)
(3) S furnace, dummy walls over chequers (Fig.2). Total flow 385 300 ft³/h						
D	1·0	1·4	1·9	1·6	2·2	8·1
C	4·2	4·7	6·4	5·3	3·4	24·0
B	4·7	7·2	5·8	7·3	4·0	29·0
A	7·6	8·6	8·3	8·1	6·3	38·9
Total (ideal = 20%)	17·5	21·9	22·4	22·3	15·9	100·0
Upflow						
(1) D furnace, clean. Total flow 452 400 ft³/h						
D	7·5	7·7	8·1	8·6	9·1	41·0
C	3·9	4·9	7·0	7·7	7·3	30·8
B	0·9	2·3	4·4	5·5	8·0	21·1
A	−1·1	1·4	2·7	3·2	0·9	7·1
Total (ideal = 20%)	11·2	16·3	22·2	25·0	25·3	100·0
(2) P furnace, 'straightener' walls (Fig.1). Total flow 544 200 ft³/h						
D	4·7	2·6	5·1	4·1	8·8	25·3
C	6·5	7·4	5·7	5·8	8·1	33·5
B	4·7	4·8	6·9	8·6	7·9	32·9
A	−1·1	3·5	1·6	3·1	1·3	8·3
Total (ideal = 20%)	14·8	18·2	19·3	21·6	26·1	100·0
(3) S furnace, dummy walls over chequers (Fig.2). Total flow 504 900 ft³/h						
D	2·0	1·9	7·0	7·0	8·6	26·5
C	5·3	5·7	7·1	7·2	8·4	33·7
B	4·8	3·9	4·8	6·0	6·5	26·0
A	0	3·2	2·3	3·4	4·9	13·8
Total (ideal = 20%)	12·1	14·7	21·2	23·6	28·4	100·0

Note: Where figures are shown in parentheses, this implies that there was reversed (negative) flow in at least one of the flue sections involved. In such cases the figures are net values and do not include the (unmeasured) negative flow to the previous section.

TABLE IV Ratio of downflow, %, to upflow, %, or vice versa

(In each case the ratio given is that of the larger to the smaller value. D/U signifies downflow/upflow and U/D signifies upflow/downflow.)

Area reference (*see* Fig.4)	1	2	3	4	5	Overall
D furnace, clean						
D	Negative	Negative	Negative	Negative	Negative	Negative
C	1·15 U/D	1·08 U/D	2·70 U/D	3·45 U/D	8·35 U/D	2·27 U/D
B	7·90 D/U	4·22 D/U	2·59 D/U	1·53 D/U	1·54 U/D	1·98 D/U
A	−5·91 D/U	5·93 D/U	3·59 D/U	3·72 D/U	9·11 D/U	6·29 D/U
Overall	1·52 D/U	1·38 D/U	1·07 D/U	1·11 U/D	1·76 U/D	1·00
P furnace, 'straightener' walls (Fig.1)						
D	5·89 U/D	5·30 U/D	3·45 U/D	10·00 U/D	∞ U/D	7·70 U/D
C	1·92 U/D	1·37 U/D	1·10 D/U	1·05 U/D	2·50 U/D	1·41 U/D
B	1·15 U/D	1·75 D/U	1·48 D/U	1·25 U/D	1·92 U/D	1·02 D/U
A	−5·28 D/U	2·70 D/U	5·10 D/U	3·74 D/U	3·54 D/U	4·73 D/U
Overall	1·05 U/D	1·29 D/U	1·37 D/U	1·13 D/U	2·17 U/D	1·00
S furnace, dummy walls over chequers (Fig.2)						
D	2·00 U/D	1·35 U/D	3·70 U/D	4·35 U/D	3·85 U/D	3·22 U/D
C	1·27 U/D	1·22 U/D	1·11 U/D	1·35 U/D	2·50 U/D	1·41 U/D
B	1·02 U/D	1·85 D/U	1·21 D/U	1·22 D/U	1·61 U/D	1·11 U/D
A	∞ D/U	2·69 D/U	3·60 D/U	2·38 D/U	1·29 D/U	2·82 D/U
Overall	1·45 D/U	1·49 D/U	1·06 D/U	1·06 U/D	1·79 U/D	1·00

Distribution on flow to chequers

Flow distributions are given in Table III for the 20 equal sub-areas of chequerwork shown in Fig.10. The overall transverse and longitudinal distributions are shown in Fig.11. These graphs correspond to the overall figures given in Table III.

In addition to confirming the points already made on recirculation, the following are apparent:

Downflow, transverse The wall used in S furnace improves the distribution, while P is worse than D. Transverse distribution is more or less symmetrical; its lack of uniformity is probably due mainly to the variation of chequer area with height, and to conditions above the chequers as discussed under recirculation.

Downflow, longitudinal The very poor distribution found in the plain regenerator (D) is improved by the walls used in both P and S, the latter being slightly more effective. The distribution found in the case of D confirms the patterns found in water models, including recirculation.

Upflow, transverse There is a marked lack of symmetry in all cases, because the flow in the main flue tends to hug the outside of the bend. It is not clear why the walls placed above the bridge in P should improve the transverse distribution on upflow; the possibility of experimental error cannot be ruled out, since in all cases of upflow the flow was 'gusty' due to 'breakway' on the inside of the bend in the main flue giving rise to turbulence.*

Upflow, longitudinal The distribution seems to be improved by the walls used in both the P and S furnace trials, the latter seeming more effective.

Combination of upflow and downflow

As was done in the section headed 'Combination of downflow and upflow', the ratios of the flow percentages to the 20 equal areas of Fig.10 are given in Table IV. Again the ratio has been expressed in the form larger/smaller flow, irrespective of whether the upflow % or downflow % was in fact the greater. In interpreting Table IV the greater the departure of the ratio from the value 1·0, the poorer would be the performance expected in practice from that portion of the regenerator. Negative values, indicative of recirculation on either upflow or downflow, would also be expected to lead to poor performance.

The frequency of occurrence of ranges of values of the ratio are given in Table V, and are shown in graphical form in Fig.12. This shows that the overall performance to be expected in practice would be, in ascending order, D, P, and S.

Trial (4) D furnace, dirty

In trial (4), the first chronologically, the data obtained were incomplete owing to a number of unforeseen circumstances curtailing the time available for useful measurements. Accordingly it is not possible to treat the data in the same manner as that adopted above.

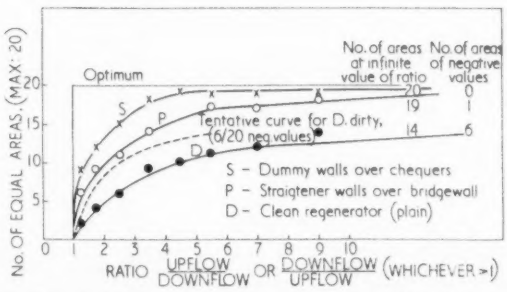
The measurements of total flow in the bearer block flues are given in Table VI, and, where possible, the derived rates of flow to the chequer areas served by the ¼ sections of the flues in Table VII, expressed as percentages of the total flow. (Note that these do not correspond to the 20 equal sub-areas of Table IV.)

* Reverse flow was qualitatively observed on the inside of the bend on upflow. The air also seemed to 'bounce' off the floor of the flue some distance from the reversal valve.

TABLE V Frequency of occurrence of values of ratio U/D or D/U as listed in Table III

Range of U/D or D/U	D furnace, clean	P furnace (Fig.1) 'straightener' walls	S furnace (Fig.2) dummy walls over chequers
1·0– 1·5	2 (2)	6 (6)	9 (9)
1·5– 2·0	2 (4)	3 (9)	3 (12)
2·0– 3·0	2 (6)	2 (11)	3 (15)
3·0– 4·0	3 (9)	3 (14)	3 (18)
4·0– 5·0	1 (10)	0 (14)	1 (19)
5·0– 6·0	1 (11)	3 (17)	0 (19)
6·0– 8·0	1 (12)	0 (17)	0 (19)
8·0–10·0	2 (14)	1 (18)	0 (19)
10·0	0 (14)	1 (19)	1 (20)
Negative values	6 (20)	1 (20)	0 (20)

Note: Figures in parenthesis are cumulative values.



12 *Cumulative frequency of occurrence of flow ratio values*

TABLE VI Trial 4, total flows in bearer block flues, D furnace, dirty (Rotherham end)*

Flue no.	1	2	3	4	5	6	7	8	9	Total
	Downflow									
¾	...	16000	14000	...	6000	...	45600	...	...	...
½	...	27600	31800	25300	21800	41600	45900	41000	...	...
¼	...	29000	44000	...	26500	...	41500	...	...	...
0	(4000)	22700	26900	25900	25000	37900	34700	39900	(15700)	232700
	Upflow									
¾	...	...	17600	...	9900	...	41700	...	...	...
½	...	27600	25400	23500	24200	40000	48900	40200	...	...
¼	...	35300	38400	...	30600	...	46500	...	...	...
0	41800	45000	38400	28700	37000	43500	50000	62400	39800	387100

* The flues are numbered from right to left for the sake of conformity with trials 1–3. Thus, in every case, flue no.9 corresponds to the outside of the bend in the main flue.
The figures given in parentheses were derived from the readings of a previous trial, later abandoned, by proportion.

The approximate positions of the overall transverse and longitudinal distributions are shown dotted on Fig.5. The transverse curves were evaluated after the manner of trials 1–3, but the longitudinal ones were based on flues 3, 5, and 7 only. It will be seen that oxide deposits can be more effective than walls in altering the flow distribution, particularly that for the longitudinal distribution in downflow. It is interesting to speculate whether at some stage during the campaign the longitudinal distributions approached the ideal: if such were the case maximum air preheat might be anticipated at this time.

It will be noticed in Table VII, and also Fig.11, that on downflow the negative flow (recirculation) occurs in the area where it might be least expected. It was thought at first that this apparent anomaly might be due to experimental error. However, it was also noticed that the longitudinal distribution was similar on both upflow and downflow, so consideration was given to the possibility of chequer blockage, due to oxide giving rise to such a situation. It is conceivable, allowing that longitudinal flow within the chequers is possible, that deposits in the area shown in Fig.13 may give rise to this type of flow. In fact visual inspection of the top of the chequerwork had shown that the actual blockage was of this character. It was estimated that nearly all the openings in that half of the chequer top remote from the bridge wall were blocked,* as was the case also with the two rows adjacent to the bridge wall and to the side walls.

It was not possible to calculate upflow/downflow ratios for the 20 equal sub-areas of Fig.4, but 20 values for smaller areas (served by parts of single flues) were available. The results of a count of values in various ranges are shown dotted in Fig.12. This suggests that more effective use is made of the unblocked parts of a dirty regenerator than in the case of a clean one. This result would be expected owing to the crowding together of the flow lines, but further trials are required to confirm this.

* This was done by directing a light upwards from the burner block flues and noticing the positions in which it could be seen from above.

TEMPERATURE MEASUREMENTS IN A WORKING REGENERATOR

It might be argued that the distribution of air and waste gases in a working regenerator will be improved by buoyancy effects. In our view, the results obtained in cold trials represent the worst possible conditions which could occur in practice, but buoyancy is insufficient to bring about a uniform distribution. In view of the difficulties inherent in attempting to measure velocity distributions in a hot working regenerator it was decided to determine whether temperature measurements could throw any light on the matter.

Thermocouples of 19 swg, chromel–alumel wire, were installed opposite the following chimney flues, numbering from the open end of the bearer arch flues, in all four bearer arch flues of L furnace at works 1: 1, 6, 11, 16, 21, and 27.

The thermocouple wires were looped round nails embedded in the side walls, and the thermojunctions were arranged to be at the centres of the bottom of the vertical chimney flues enumerated above. The thermocouples were connected by compensating cable to a 12-point high-speed recorder.

Although the thermocouples failed, one by one, sufficient readings were obtained to enable a comparison of results in each of the four flues to be made.

The mean temperatures of each half cycle are shown in Table VIII.

It is clear that the temperatures assumed by the thermocouples will be intermediate between those of the air and waste gases, and the brickwork.

If the air and waste gas distributions in a working

TABLE VII Partial flow distribution, trial 4, expressed as percentage total flow

Flue no.	1	2	3	4	5	6	7	8	9	Total
Downflow										
D	...	6·9	6·2	10·9	2·6	17·9	19·6	17·6	...	...
C	...	5·0	7·5		6·8		0·1		...	...
B	...	0·6	5·3	0·3	2·0	−1·6	−1·9	−0·5	...	...
A	...	−2·7	−7·4		−0·6		−2·9		...	...
Total	1·7	9·8	11·6	11·2	10·8	16·3	14·9	17·1	6·6	100·0
Upflow										
D	...	7·1	4·6	6·1	2·6	10·3	10·8	10·4	...	...
C	...		4·6		3·7		1·8		...	...
B	...	2·0	3·3	1·3	1·7	0·9	−0·6	5·7	...	...
A	...	2·5	0		1·7		0·9		...	...
Total	10·9	11·6	9·9	7·4	9·7	11·2	12·9	16·1	10·3	100·0

TABLE VIII Average temperatures, °C of thermocouples in chimney flue bottoms

Bearer arch flue no.	1		2		3		4	
*Chimney flue no.	Air cycle	Gas cycle	Air cycle	Gas cycle	Air cycle	Gas cycle	Air cycle	Gas cycle
27	375	540	280	450	310	530	375	540
21	410	660	...	...	410	550	...	...
16	...	...	340	590	...	...	385	540
11	550	720	...	...	505	630	...	...
6	550	720	310	560	...	...	...	...
1	...	...	...	...	...	...	...	...

* Numbering from the open end of bearer arch flue.

regenerator are similar to those encountered in the cold trials the following trends would be expected:

(i) the average temperature of the brickwork near the bottoms of the chimney flues would be expected to decrease from the open to the blind end of the bearer arch flues. This would lead to a similar trend in thermocouple reading

(ii) since most of the air flows to the blind end of the bearer arch flues, it would be expected that the thermocouples in this region would assume a value nearer the true air temperature, i.e. a lower value

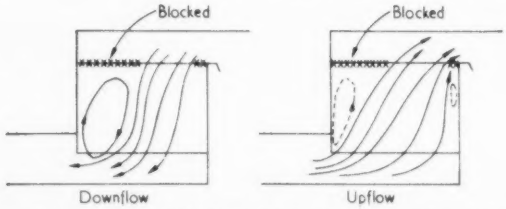
(iii) conversely, since most of the waste gases flow down flues near the open end of the bearer arch flues, the thermocouples here would be expected to show higher readings.

Owing to all three causes, the thermocouples would be expected to show decreasing average temperatures from the open end to the blind end on both waste gas and air flow.

Of the results in Table I, those for flues 1 and 3 support the above ideas, those for flue 4 are not contradictory, but those for flue 2 are somewhat anomalous. This could be due to any of the following reasons: (i) contamination of the couple, resulting in a false output; (ii) unsatisfactory positioning of the thermojunction; (iii) some unusual, local, distribution not brought out by the cold experiments.

Observation of conditions on top of the chequerwork during waste gas cycles, when hot metal charging increased the emissivity of the gas, confirmed that the type of distribution found in the cold experiments, was in fact obtained. The results indicate clearly that the thermocouples gave readings very different from the air and waste gas temperatures. For example, in the case of flue 1, the individual temperatures on air decrease from 550°C at the open end to 375°C at the blind end. It is extremely doubtful whether these values would be achieved by the air in the bearer arch flues, and in any case, the air temperature must increase from the open to the blind end.

The results show that the type of maldistribution found in the cold trials is also present in a working regenerator.



13 *Suggested partial blockage of flues giving rise to flow pattern found by experiment*

CONCLUSIONS

The technique of determining flow distribution by means of flow measurements made in a cold regenerator shows that considerable maldistribution of flow can occur. Such maldistribution in a working regenerator would considerably impair the efficiency of heat recovery and the air preheat obtained. It is particularly unfortunate that the regions of high upflow correspond to those of low downflow and vice versa. Although the results of the cold trials probably give a worse distribution than that which would obtain in a hot regenerator, temperature measurements have shown in a qualitative manner that the same type of non-uniform distribution occurs in a working regenerator.

The flow distribution in a regenerator can be improved by the provision of suitable baffle walls. The optimum placing of such walls can be determined on an *ad hoc* basis by the technique described. The success of such baffle walls in practice may be judged by the results achieved at one works and described in the paper by Chapman and Montgomery, in which something like 150°C extra preheat was obtained with a saving of about 1½ gals oil/ton steel made.

This paper also confirms the validity of the technique for assessing distribution.

The results obtained suggest that if it were possible to modify the arrangement of regenerator flues, considerable improvement in performance could ensue.

The modification would consist of siting the main 'fantail' flue at the bottom of the setting on the same side as the slag pocket, so that both waste gases and air enter and leave the regenerator from the same side. This arrangement should result in a distribution in which regions of high downflow correspond with those of high upflow. It is of course appreciated that on some sites such an arrangement might be difficult, if not impossible; nevertheless the suggestion is put forward for serious consideration in all cases where site difficulties are not insuperable.

The results of the trial of a dirty regenerator suggest that partial blockage of a regenerator can result in improved distribution. It seems likely that the nature of the distribution changes progressively throughout a furnace campaign as blockage proceeds.

There is yet scope for much further work in this field, since it seems likely that the blockage of the regenerator flues will not necessarily be very closely related to the flow distribution.

ACKNOWLEDGMENTS

The kindness of the management and staff of Messrs John Summers and Sons Ltd, and Steel, Peech and Tozer in permitting the trials described is gratefully acknowledged, as is also that of Messrs Dorman Long Ltd and Samuel Fox Ltd, where trials, the results of which are not included in this paper, were also carried out. Thanks are also due to Messrs Pluck, Chapman, and Mayorcas for their enthusiasm, encouragement, and help. Finally, no praise is too high for Dr P. L. Start and Mr J. Rhydderch, of this department, for their cooperation in the trials, often under most uncomfortable and arduous conditions.

A model study of splashing

Kun Li

SYNOPSIS

In an attempt to find ways of reducing splash in an oxygen-blown furnace, a simple model system with a fluidized liquid and an impinging jet has been used to study the effect on splash pattern of lance angle, lance height, and jet flow rate. Some interesting and surprising phenomena have been observed. These include the dramatic influence of the conditions of a foam layer on the top of a liquid on the amount and size as well as the distribution of droplets, and the pronounced differences between jetting and lancing, the latter generally producing far less splash.

It is hoped that results obtained in such a system, although far from ideal, might (a) *indicate further refinements of the model system to give closer simulation of the splashing process and* (b) *prove useful in suggesting, in a qualitative sense, possible improvements in practical operation.* 1893

INTRODUCTION

ONE OF THE serious disadvantages in using oxygen in an open-hearth furnace to increase the production rate is excessive roof wear and hence high roof costs. There has been evidence to show that excessive roof wear is caused mainly by metal and slag particles rising from the bath and splashing on to the roof. In a series of experiments[1] carried out in an oxygen-blown OH furnace it was found that the iron oxide deposit on the roof was several times greater directly above the lance during oxygen blowing than the deposits found in normal practice even at positions of maximum wear, and that the ratio of the deposits above the lance to those in the centre of the roof was about 4·5:1. Another series of experiments[1] conducted under comparable conditions showed that the rate of roof wear in the areas directly above the lance was several times greater than in the centre of the roof and that in all cases, wear rate was much greater than in normal practice without oxygen blowing. With ever-increasing demand for higher output rate at lower cost, it is desirable to find ways and means of prolonging furnace refractory life.

The use of a model was proposed to find methods of reducing splash. However, short of using a 'baby' furnace, it is virtually impossible to simulate completely the splashing process which is influenced by a complexity of mass, heat, and momentum transfer processes in a furnace. Furthermore, these processes are unfortunately of an unsteady-state nature as the properties of the system change continually during the progress of refining, a feature which cannot be adequately simulated by a physical model.

In addition a model study cannot be effectively and usefully carried out unless either the mechanism of the process is well understood or at least the variables affecting the process are known. Two mechanisms have been suggested to explain the splashing process in an OH furnace without oxygen blowing. In the first, the ejection of droplets from the molten steel bath is said to be caused primarily by the rising CO gas, which rips the liquid metal into droplets by impact and carries them upwards. The second, on the other hand, postulates that droplets are formed and ejected by excess energies given off by CO bubbles when bursting at the surface of the bath. The merit of either mechanism is difficult to assess owing to complete lack of experimental evidence and it is likely that the droplets arise from a combination of both mechanisms. Leaving out the thermal and chemical aspects and assuming that one mechanism is predominant, the problem of modelling the splashing process remains a difficult one without adequate information as to the nature of bubble nucleation, and size and distribution of bubbles and droplets. Use of an oxygen jet only further complicates the task in that the jet probably distorts both mechanisms in a highly complex manner.

Because of the many unknown elements involved, a 'trial-and-error' technique must be used, starting with

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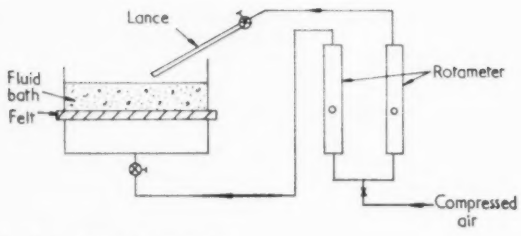


1 *Experimental apparatus*

a simple model system which, although far from reality, might provide quite useful information. Numerous splashing tests were first made in a simple and crude system consisting of a fluidized water bath and an impinging air jet. It is hoped that the results of the present study will provide some clues as to the important factors which may then lead to more refined experiments. In addition to the results from the air–water system, accounts of other attempts are reported here as a reference for future work.

EXPERIMENTAL WORK

Model system

The first idea of using a gas–solid fluid bed was rejected after a few tests which showed that such a system possessed no surface tension properties. A fluidized slurry was tried next. It was found that a slurry made of polystyrene beads and machine oil in suitable proportion, when aerated produced a state which resembled an OH 'boiling' bath. By varying the percentage of solid, and hence the viscosity of the slurry, it was possible to change the appearance of 'boil'. This system had to be abandoned, principally because no satisfactory method was found for recording and analysing splash patterns made by a slurry. Practical difficulty in handling a slurry was another disadvantage.

For the purpose of obtaining measurable splash patterns, slurry was replaced by glycerine, the viscosity of which can be varied by the addition of water. Unfortunately a new difficulty was encountered. Because the compressed air contained considerable moisture as well as dust, and glycerine is highly hygroscopic, it was not possible to maintain a constant state of fluidization or to obtain reproducible splash patterns since the properties of glycerine were continually changing during an experiment.

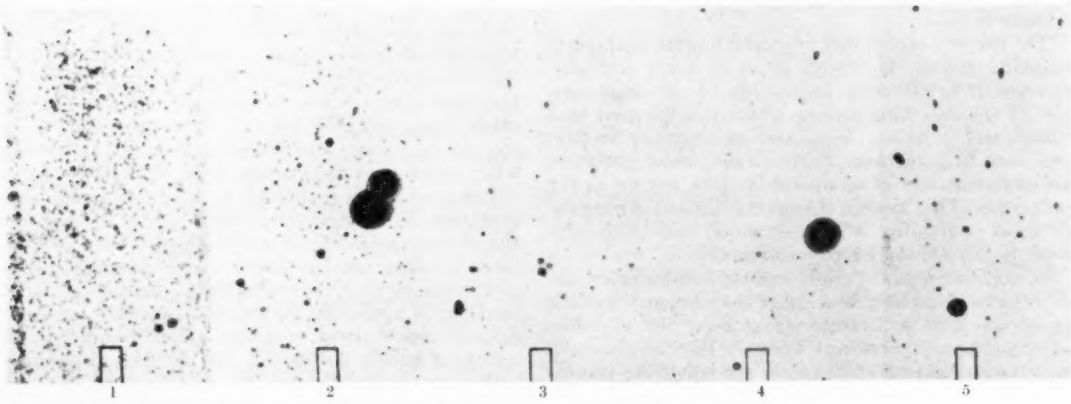
Meanwhile, tests made in an air–water system had shown some interesting results. It was, therefore, decided to pursue the study of this system more fully.

Splash sampling and determination

A literature survey revealed two techniques for sampling liquid droplets. Garner *et al.*,[2] in a study of entrainment, used MgO-coated microscope slides on which well defined impressions were left by striking droplets. In the second technique used by Aiba and Yamada,[3] species of bacteria were suspended in the liquid so that the droplets, collected on a glass slide, left ring-shaped stains formed by the bacterial cells aligned along their circumference. The stains were then coloured with methylene blue solution. In both cases, the distribution of droplets was determined by actually counting the number and measuring the size of droplets under a microscope. The first technique of sampling droplets was thought suitable and explored, but the method of determining droplet distribution was considered too laborious and lengthy, so an alternative method using a photocell was investigated.

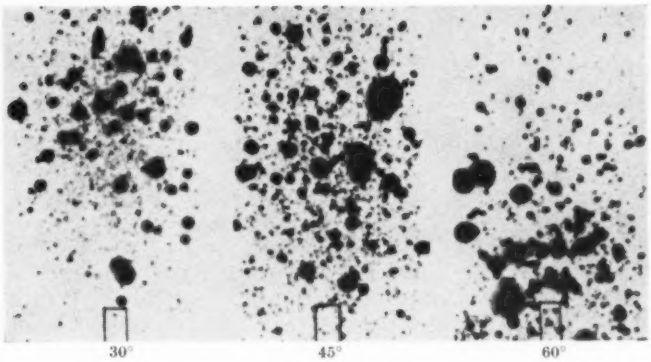
It was found that although the oil–polystyrene slurry as well as glycerine tended to spread on a MgO-coated slide leaving smeared impressions, the original impressions made by the striking droplets were clearly visible when the slide was examined in a photographic enlarger.

The photocell method for determining splash pattern is based on the principle that the degree of transparency to light of a MgO-coated slide is varied when a droplet strikes its surface and the extent of variation depends on the size and frequency of droplets; thus the difference in photocell readings of a slide before and after exposure to splashing droplets will be proportional to the amount of splash, and the splash pattern can be established by dividing the slide into



1 uniform and 'fine-grained', $\frac{3}{4}$ in. thick 2 froth layer beginning to form on top of foam
3 froth layer attached to foam growing to $\frac{1}{4}$ in. thick 4 froth layer becoming slightly detached
5 froth layer becoming partly detached

2 *Splash patterns from different foam conditions*



Lance slant height $\frac{1}{4}$ in.; bath flow rate 0·186 ft³/min; jet flow rate 0·397 ft³/min

3 *Splash patterns at different lance angles*

small areas and measuring the difference in each area.

An apparatus was constructed in which a selenium-barrier-layer photocell with a 0·5-in. sq. opening was made to traverse the entire area of a sample slide, a light source housed in a box was provided by 12 flash-light bulbs, and the output of the photocell was recorded on a Honeywell-Brown recorder. Many readings were taken with test slides, but the results were not at all encouraging. Repeated traverses were not found to give reproducible readings, and readings of the same area over a prolonged period also showed irregular variations. This was first thought to be caused by variation in light intensity and photocell drift. The apparatus was modified to include two constant voltage regulators for the light source and another identical photocell in the background to compensate for the drift. For reasons not clearly understood, the modifications only resulted in minor improvements and the variations still exceeded the tolerable limits.

Because of this failure and the fact that the desired accuracy in this work did not warrant the lengthy procedure of counting the number and measuring the size of droplets, a relatively simple technique was adopted. A piece of filter paper was exposed for a given length of time to the splashing liquid coloured with ink or food colouring and the splash pattern examined by visual inspection.

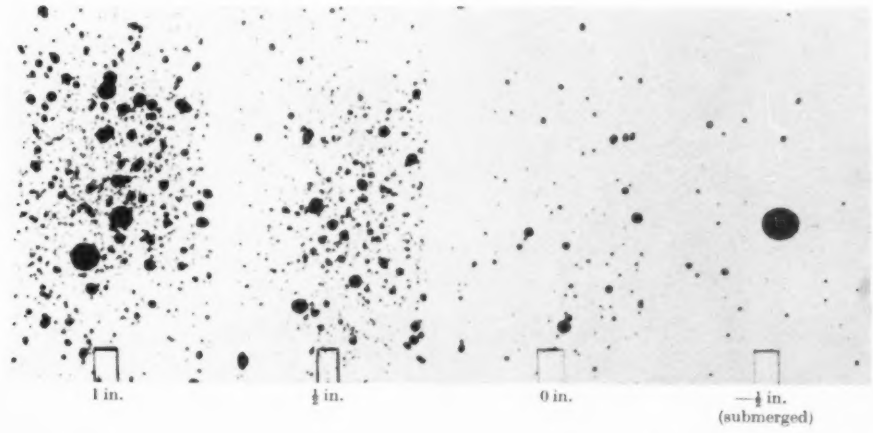
Apparatus and procedure

Geometrical similarity was ignored in the design of the apparatus, owing to its exploratory nature. The apparatus is shown in Fig.1. It consists of a rectangular perspex box with a piece of felt inserted and a lance. The inside dimension of the box was 3 in. × 8 in. and the height from the felt to the top edge was $4\frac{21}{32}$ in. The felt, $\frac{9}{16}$ in. thick, was a material normally used for damping machine vibrations. It gave fairly uniform distribution of air bubbles. The lance was a straight copper tube threaded at one end to take a nozzle and was held by a mechanism which permitted angular and axial movements. Air streams to the liquid bath and to the nozzle were metered individually through two rotameters.

Before starting a run, the felt in the perspex box was first moistened and excess water removed by blowing with the mouth. This procedure was found necessary to prevent soaking of the felt by water during the run. For each setting of conditions, the splash pattern was taken by placing a piece of filter paper flat on the open top of the box and exposing it for 1 min. Exposures were repeated in many cases.

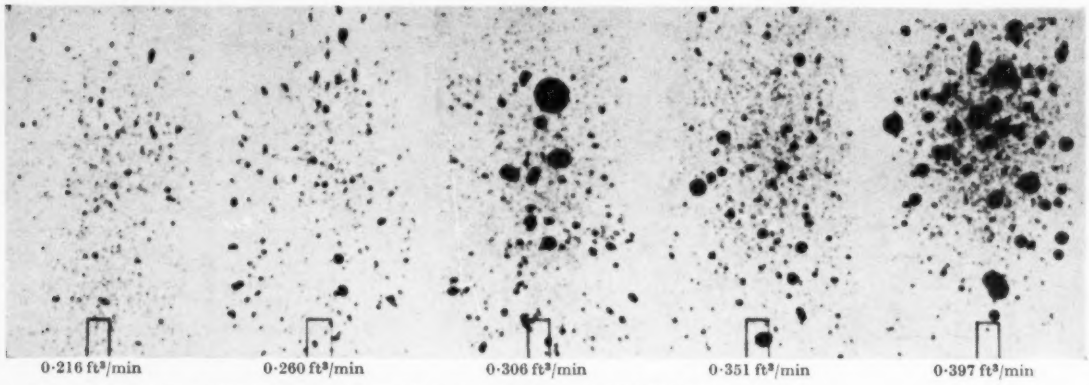
To minimize variations caused by differences in foam condition, air was allowed to bubble through the liquid bath for over 1 h before taking splash patterns.

The amount of ink or food colouring added to the water (just sufficient to produce visible splash patterns), did not alter the viscosity, surface tension, or density of the water.



Lance angle 45°; bath flow rate 0·186 ft³/min; jet flow rate 0·306 ft³/min

4 *Splash patterns at different lance slant heights*



Lance angle 30°; lance slant height ¼ in. (above the bath); bath flow rate 0·186 ft³/min

5 *Splash patterns at increasing jet flow rate*

Results

In all experiments, only one nozzle size of $_{16}$ in. dia. was used. The bath depth varied from 1¼ in. to 1½ in., but this variation did not result in detectable differences in splash pattern and may therefore be neglected.

Over 200 splash patterns were made under varying conditions. Major variables studied include:

(i) lance angle with the horizontal at 30°, 45°, and 60°

(ii) slant height of the lance (axial distance from the lance tip to the bath surface) at ½ in. below the bath surface, 0 in., ½ in., 1 in., and 1½ in. from the bath surface

(iii) jet flow rate from 0·16 to 0·5 ft³ of air per minute

(iv) bath flow rate from 0·014 to 0·19 ft³ of air per minute.

Except for the series in which the flow rate through the bath was varied, a flow of 0·186 ft³/min was used throughout.

It was accidentally observed that under identical conditions, the splash pattern with a freshly prepared solution differed considerably from that with a used solution and that in the two cases, the conditions of the foam present on the top of the liquid were appreciably different. A special series of experiments was therefore made in which splash patterns were studied as a function of time.

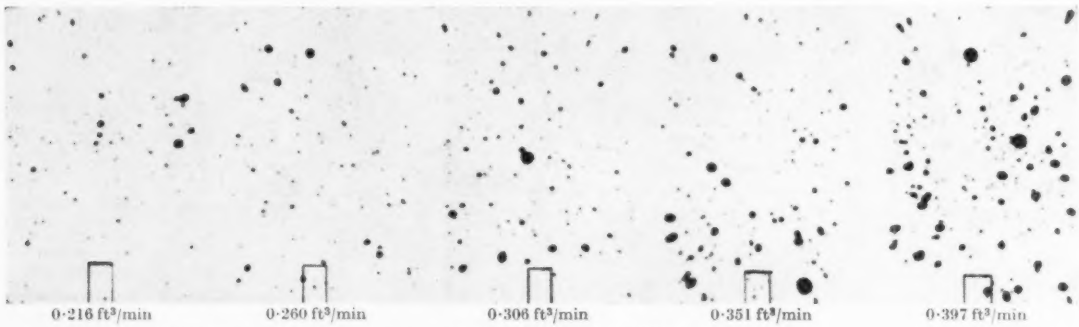
On the conditions of foam, the following general observations were made:

(i) when a freshly prepared ink solution was fluidized, a layer of uniform and 'fine-grain' foam began to form on the surface of the bath. The thickness of this foam layer depended on the air flow rate through the bath

(ii) after about 1 h of fluidization, a second froth-like layer formed on the top of the foam layer. When it first formed, this froth layer was completely attached to the foam layer but it gradually became slightly detached with large air pockets separating the two layers. The froth layer appeared to grow in thickness with time of fluidization

(iii) depending on the jet flow rate the thicknesses of the foam and the froth layers, as well as their distribution, were generally altered. At low jet flow rates, there was usually a build-up of the froth layer towards the end walls and the froth layer was nearly completely detached from the foam layer, whose thickness remained more or less unchanged. At high jet flow rates, the froth layer disappeared, except in the region near the wall behind the lance.

In one series where no jet was blown over the bath and the bath flow rate was varied, splash patterns were taken with MgO-coated slides and examined in an enlarger. The slide taken at a bath flow rate of 0·014 ft³/



Lance angle 30°; lance slant angle −¼ in. (submerged); bath flow rate 0·186 ft³/min

6 *Splash patterns at increasing jet flow rate*

min showed clear impressions of solid and hollow droplets and numerous faint impressions. The size of droplets as measured from the impression varied from 100 μ to 300 μ. Many hollow droplets had 'tails' suggesting that they had skidded on the slide before bursting. As the bath flow rate increased, the number of droplets decreased but there was a slight increase in size. This is interesting because fume samples collected in an OH furnace have been found to contain a large number of hollow spheres with an iron oxide shell.[4]

DISCUSSION OF EXPERIMENTAL RESULTS

In analysing splash patterns by visual inspection, it is assumed that the size of droplet is proportional to the size of impression and that the shade of impression is indicative of the frequency of droplets. Although the conditions of foam were found to have important effects on splash pattern, it is not possible to provide the details for each individual run, beyond the general description given in the previous section.

Conditions of foam

The conditions of foam have considerable effect not only on the size and number but also on the distribution of droplets. This is well illustrated by the splash patterns taken as a function of time but under identical operating conditions. The conditions were: lance angle 60°, lance slant height 0 in. from the bath surface, jet flow rate 0·306 ft³/min, bath flow rate 0·186 ft³/min. Starting with a freshly prepared ink solution, the foam layer was observed to have changed from a uniform rigid and 'fine-grained' structure, about $\frac{3}{4}$ in. thick, to a final and steady state where a semi-detached froth layer about $\frac{1}{4}$ in. thick formed on the top through stages of gradual transformation. No change in thickness of the foam layer was noted. The corresponding splash patterns, as reproduced in Fig.2, are seen to have changed from a uniform distribution of small droplets to a scattering of larger but much fewer droplets. This dramatic change may conceivably occur in practice when the state of slag undergoes changes.

Lance angle

The effect of lance angle on the splash pattern cannot be generalized without reference to the lance slant height. At the lance slant height of zero, i.e. the lance tip touching the surface of the bath under static conditions, a lance angle of 45° seems to give fewer droplets than at 30° or 60°. Their sizes are similar to those at 30°. Larger droplets are found at 60°. When the lance is submerged, the splashing is least at 45°; the number of droplets is far less than that at 30° and roughly equal to that at 60°, but the droplets are relatively small compared to those at 60°. Some of the droplets at 60° are extremely large, much larger than those at 30°. On the other hand, at the lance slant height of $\frac{1}{2}$ in. from the bath, the splashing at 45° appears slightly heavier than either at 30° or 60° although no obvious difference in size distribution is noted. When the lance is further away from the bath at a slant height of 1 in., the 45° lance angle produces the heaviest splashing and the droplets are more concentrated in one area.

This seems to suggest that there exists a dividing point at the lance height of zero, above which the splash pattern follows one relationship with the lance angle, and below which it follows another.

In general, as the lance angle is increased, the splashed area moves towards the lance. This can be clearly seen from the splash patterns shown in Fig.3.

Lance slant height

At the lance angle of 30°, the amount of splash varies with the lance slant height in the order: $1\frac{1}{2}$ in. $\cong 1$ in. $\cong \frac{1}{2}$ in. > 0 in. $> -\frac{1}{2}$ in. The minus sign indicates that the lance is submerged and the figure the slant distance of submersion. At 45°, the order is: 1 in. $> \frac{1}{2}$ in. > 0 in. $> -\frac{1}{2}$ in. and at 60°: 1 in. $\cong \frac{1}{2}$ in. > 0 in. $> -\frac{1}{2}$ in.

Here again, the point of zero lance height seems to divide the splash patterns into two categories. Far greater numbers of small droplets are produced when the lance is raised above the bath. The amount of splash is sharply decreased when the lance touches the bath surface. Four splash patterns taken at 45° and varying lance slant height are shown in Fig.4.

Jet flow rate

Splash patterns can be again roughly divided into two groups:

(i) with the lance above the bath
(ii) with the lance submerged including the position of zero lance height.

In addition consideration must also be given to the lance angle.

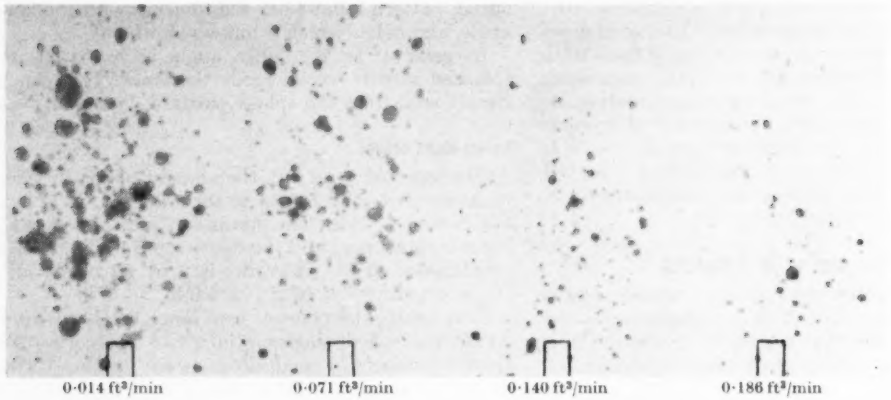
In the first group where the lance is above the bath, both the number and the size of droplets increase with increasing jet flow rate, varying from a fine spray of small droplets to a heavy splash by small as well as large droplets (Fig.5). In contrast, splash patterns in the second group show that the number, but not so much the size of droplets, increases with jet flow rate (Fig.6).

Figures 5 and 6 also illustrate the general trend in both groups: the area of heavy splash tends to move away from the lance (indicated on the slides) with increase in jet flow rate. However, this effect is not found to be so evident in the following cases: 30° and 1 in., 60° and all levels of lance height.

The lack of this general trend at 60° lance angle may be explained by the consideration of the relative magnitudes of forces exerted on a droplet. At 60° the jet, if assumed to be deflected at the same or smaller angle, results in a greater component force in the upward direction than in the horizontal. Combined with the bath flow, the upward forces become a predominating factor on the path of the droplet. Unfortunately this argument leaves unexplained the fact that this shifting is not displayed by the splash patterns at 30° and 1 in. while it is so evident at 45° and 1 in. This could only mean that the forces acting on a droplet are far more complex than indicated in this simple analysis.

Bath flow rate

Owing to difficulties in regulating the flow rate, only a limited number of runs was made at 45° lance angle and $\frac{1}{2}$ in. lance slant height. At low jet flow rates, the number of fine droplets decreases rapidly with increase in bath flow rate. At high jet flow rates the number of fine as well as large droplets decreases as the bath flow rate increases (Fig.7). It was observed



Lance angle 45°; lance slant height $\frac{1}{8}$ in.; jet flow rate 0·306 ft³/min

7 *Splash patterns at increasing bath flow rate*

that when the bath flow rate was increased from 0·014 to 0·19 ft³/min, the thickness of the foam layer increased from almost zero to about $1\frac{1}{8}$ in.

CONCLUSIONS

While it is not possible to simulate completely the splashing process in an oxygen-blown furnace, experiments with a simple and 'primitive' model system have provided some interesting and perhaps useful information.

Two important conclusions may be drawn from the results of this work:

1. A foam layer present on the top of a liquid plays an important role on splash pattern. In general, it produces a damping effect on splashing droplets. Depending on its conditions, this foam layer affects not only the amount but also the distribution of droplets. This gives reason to believe that the conditions of slag may likewise affect splashing in an actual furnace. It has in fact been observed[5] that the presence of slag influences the amount of fume emitted which decreases with increasing slag thickness. Although there exists no direct experimental evidence to link splashing with fuming, it is conceivable that fume may in part arise from splashing droplets. The effect of slag may be more fully studied in a model system in which the slag layer is simulated by a second liquid.

2. Variations in splash pattern with lance angle, lance slant height, and jet flow rate are shown to follow two different relationships and possibly two different mechanisms with the position of zero lance height as a dividing point. Lancing (with the lance submerged) generally produces less splash than jetting (with the lance above the surface). Limited evidence in an actual furnace tends to confirm this. Hence it would appear preferable to consider lancing and jetting as two distinct processes and to study them on a separate basis.

To achieve closer similarity sufficient plant data pertaining to splashing should be collected and analysed so that some plausible mechanism and hence similarity criteria may be devised on which the choice of model system and design of model experiments depend. As a means of gaining more than qualitative information, some method of quantitative determination of the amount and size distribution of splash should be sought and developed, for example, a soluble dye technique.

In practical application the first conclusion points to the suggestion that one possibility of reducing splash lies in creating a favourable slag by changing either its composition or operating conditions; however, the new slag must be equally effective from the metallurgical standpoint. Advantage may be taken of the fact that a sharp reduction in splash occurs as the lance is lowered to touch the bath surface.

It is important to point out that any possible improvements in plant operation indicated by the results of this work should be considered in the light of other metallurgical aspects of the process, for example, oxygen efficiency and transfer rate, and fume production.

ACKNOWLEDGMENTS

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Influence of alloying elements on the first stage of tempering in high-carbon steels

H. W. King, B.Sc., Ph.D. and S. G. Glover, B.Sc., Ph.D.

SYNOPSIS

The tempering of five 1%C steels which contained Si, Mn, Ni, Cr, *or* Mo *and a 1·14% plain carbon steel has been studied at temperatures from 23° to 100°C by measurements of the change in electrical resistivity. The resistance of the* Cr *and* Mo *steels decreased continuously with tempering time at all temperatures, but the resistance changes in the* Si, Ni, *and plain carbon steels exhibited a positive peak, and the* Mn *steel a point of inflection, at temperatures below 80°C. These various forms of resistance changes are considered to be associated with the effect of the alloying elements on the precipitation of ε-carbide in coherent form.*

The activation energy of the first stage of tempering has a unique value for each of the steels studied, but the values obtained for the alloy steels did not conform to the linear relationship between activation energy and carbon content previously established for plain carbon steels. Si *and* Ni *increased the activation energy, while* Cr, Mn, *and* Mo *caused it to be lowered. This variation in activation energy is discussed in terms of the influence of the alloying element on the behaviour of the carbon in solution in the martensite.* 1906

INTRODUCTION

WHILST THE mechanism and kinetics of the first stage of tempering in plain carbon steels have been the subjects of several recent publications,[1–5] study of the influence of alloying elements on the tempering of martensite has been confined mainly to the later stages of the process.[6] The influence of silicon[7, 8] and chromium[9] in retarding softening during the third stage processes, for example, has been well established, but little is known about their effect on the first stage. There have been some indications that the first stage is virtually insensitive to the alloying element content of the martensite. The additions of Ni and Cr to 1%C steels did not significantly modify the pattern of changes in various physical properties,[10] in particular dilatation,[11] during the first stage of tempering.

Lement *et al.*[12] later studied length changes in martensite aged at room temperature after various heat-treatments and found that while the magnitude of the changes was usually decreased by the addition of alloying elements, and also by the amount and conditions of the retained austenite, the addition of Cr, Mn, and W to 1%C steels did not affect the kinetics of the martensite decomposition. In further support of this, Averbach and Cohen[13] report that two steels, containing 1·07%C, and 1·00%C, 1·56%Cr and 0·2%V respectively, have roughly the same reaction rate constants, stress-relief indices, and about the same heats of reaction for these factors, namely 9050 and 7480 cal/mole. Since the addition of alloying elements to high-carbon martensites in general decreases the magnitude of the observed length changes[12, 13]; however, the method of studying the first stage of tempering developed by these investigators, and later applied with some success to plain carbon steels,[1] may well be insufficiently sensitive for the examination of alloy steels. The conclusion that alloying elements have a negligible effect on the temperature range of the reaction[14] may also be due to the relatively low sensitivity of the dilatometric technique.

This belief was strengthened by a recent investigation, by the present authors,[4] of the changes in electrical resistance during the tempering of plain carbon steels which revealed some aspects of the kinetics of the first stage process which remained undetected when the reaction was studied by following changes in structure-insensitive properties, such as changes in length. For instance, the activation energy of the first stage of tempering was shown to vary linearly with the carbon content of the martensite. The addition of alloying elements in substitutional solid solution in martensite will tend to change the environment of the interstitial carbon atoms, since in general the interactions between carbon and iron atoms will be different from that between the carbon atoms and those of the alloying element. It was of interest therefore to study the possible effect of such interactions on the activation energy for the diffusion of carbon in the martensite. Further, during the tempering of high-carbon steels at temperatures below 80°C, the resistance changes first increased and passed through a maximum, before becoming negative to follow the normal pattern associated with the removal of carbon atoms from solution in the martensite. These early peaks were related to a positive component of the observed

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TABLE I Analyses of steels

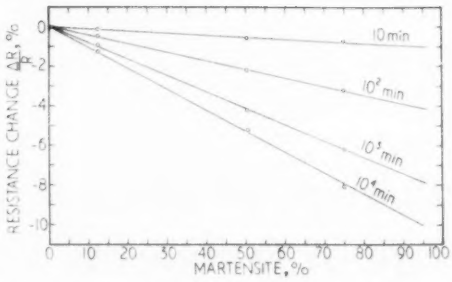
Steel	C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	Mo, %	Martensite content of quenched specimens, %
114	1·14	0·33	0·14	0·012	0·013	0·078	0·12	0·07	76·7
Si	1·12	1·78	0·025	0·009	0·015	0·01	n.d.	0·02	83·4
Mn	1·01	0·42	2·97	0·023	0·024	0·21	0·48	n.d.	62·5
Ni	1·07	0·079	0·020	0·014	0·016	5·14	n.d.	0·05	65·9
Cr	1·00	0·26	0·33	0·004	0·010	0·19	1·37	0·18	81·7
Mo	1·07	0·079	0·025	0·009	0·016	0·01	n.d.	1·00	82·9

resistance change caused by coherency strains during the precipitation of ϵ-carbide from the martensite. The magnitude of these peaks was found to be lowered with decreasing initial carbon content of the martensite and for tempering treatments at 23°C, the peak vanished at about 1·05% carbon. A study of changes in electrical resistance during the tempering of steels containing about 1%C and significant amounts of one other alloying element should enable the influence, if any, of the alloying element on the coherency strains to be evaluated. The alloying elements chosen for such a study were Si, Mn, Ni, Cr, and Mo.

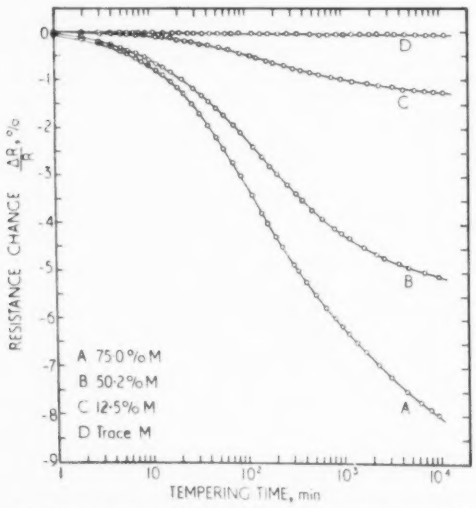
EXPERIMENTAL METHOD

The chemical analyses of the steels used in the investigation are given in Table I. The amount of alloying element added was estimated to be within its solubility limit in a 1·0% carbon austenite at 1 100°C and insufficient to cause the retention of graphite in the case of Si and Ni, or of insoluble carbides in the case of the other elements after an austenitizing treatment of 30 min at 1 100°C. This objective was achieved except in the Mo steel which exhibited a trace of finely dispersed carbide. Modification of the austenitizing temperature failed to eliminate this without resulting in grain-boundary fusion and since its effect in terms of the depletion of the solute content of the austenite was clearly slight, it was considered tolerable. A plain carbon steel containing 1·14% carbon was also included in the investigation to bridge the gap between the 0·92%C and the 1·27%C steels of the previous study.

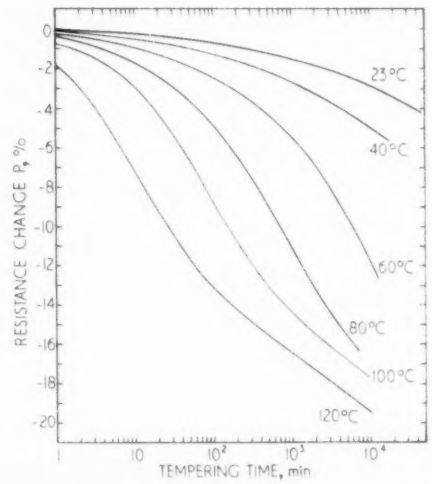
The Mn and Cr steels and steel 114 were prepared commercially and supplied in the form of 1-in. or $\frac{5}{8}$-in. dia. rolled bars. The Si, Ni, and Mo steels were prepared from high-purity materials in an Edwards vacuum melting furnace in the laboratory and hot rolled to $\frac{1}{2}$ in. dia. Quenched specimens cut from these steel stocks were examined for homogeneity, and rods 10 in. long were annealed, turned down to 0·35 in., and then swaged to 2-mm dia. wire. Specimens just over 10 cm long were cut from these wires, and after an austenitizing treatment of 30 min at 1100°C were water quenched to 20°C, except for specimens of steel Mn which were quenched to 0°C. The resistance changes at various temperatures from room temperature to 100°C, and occasionally at 120°C, were measured as a function of time using a differential potentiometric technique described previously.[4] The resistance changes were expressed as the ratio $(\Delta R/R)$ of the change in resistance to the initial resistance of the quenched steel. The martensite content of all specimens was measured at the conclusion of each tempering experiment using a Sucksmith magnetic balance, and typical values for each steel are shown in column 10 of Table I.



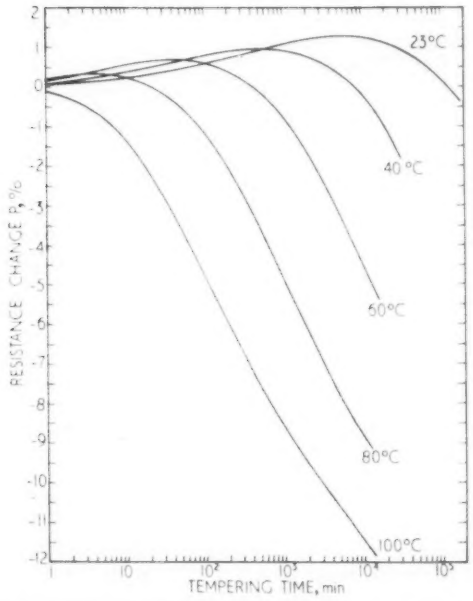
2 *Dependence of resistance changes after the times indicated on martensite content; plotted from results of Fig.1*



1 *Resistance changes during isothermal tempering at 100°C of specimens of steel* Mn *quenched to various temperatures*



3 *Resistance changes during the isothermal tempering of steel* Cr



4 *Resistance changes during the isothermal tempering of steel* Si

EXPERIMENTAL RESULTS

Influence of martensite content on resistance changes

It had been established that retained austenite, when present in plain carbon steels, made no measurable contribution to the observed changes in electrical resistance during the first stage of tempering.[4] All of the present alloy steels, with the exception of steel Mn, exhibit resistance changes *v.* tempering time curves similar in form to one or another of the previously studied plain carbon steels. To establish whether retained austenite was contributing to the observed resistance changes in steel Mn, specimens were quenched to −196°, 20°, and 60°C, and tempered at 100°C. The martensite contents of these specimens were 75·0, 50·2, and 12·5% respectively, and the observed resistance changes are shown in Fig.1. The relationship between the magnitude of $\Delta R/R$ after any given time and the martensite content of the specimen can be expressed as a family of straight lines, see Fig.2, which when produced pass through the origin, indicating that the retained austenite present does not contribute to the observed changes in electrical resistance. Further confirmation is given by the results for specimen *D* in Figs.1, and 2 which was quenched to just below the M_s temperature at 230°C, and tempered at the same temperature. On subsequent examination the specimen was found to be almost completely austenitic, the change in resistance of 0·03% after 10^4 min being caused by a trace of martensite present. The linear relationship between $\Delta R/R$ and martensite content was also established for various specimens tempered at 23°C and may be used to calculate the change in resistance, *P*, of a 100% martensite specimen after any given time by:

$$P = \Delta R/R\ 100\%\ \text{martensite} = \Delta R/R\ \text{M}\%\ \text{martensite} \times 100/\text{M} \quad \ldots\ldots(1)$$

where M is the martensite content of the tempered specimen. By expressing all resistance changes in terms of this parameter *P* any errors due to differing quenching conditions, which would cause a variation in martensite content, are eliminated, and a direct comparison is permitted between the degree of the resistance change observed on tempering different steels at the same temperature. The data in Fig.1 also show that the number of measurements made in each isothermal tempering was adequate to enable an accurate smooth curve to be drawn through the results and that the scatter of results from this curve was negligible.

TABLE II Resistivity changes during tempering of Cr and Mo steels

Steel	Tempering temperature, °C	*P* after indicated times 1 min	10 min	10^2 min	10^3 min	10^4 min	Initial rate, % min^{-1}
Cr	100	0·833	2·941	8·720	14·390	17·492	0·465
	80	0·450	1·703	4·806	11·096	...	0·243
	60	0·279	0·957	2·421	5·400	11·723	0·142
	40	0·189	0·533	1·281	2·635	...	0·065
	23	0·087	0·341	0·775	1·500	2·832	0·040
Mo	100	1·091	4·754	13·950	22·371	27·571	0·692
	80	0·250	1·395	5·511	15·339	23·870	0·179
	60	0·102	0·443	1·624	5·584	15·135	0·067
	40	0·025	0·148	0·480	1·562	4·951	0·038
	23	0·010	0·098	0·268	0·521	1·497	0·019

Steels Cr and Mo

The form of the change in electrical resistance for steels Cr and Mo is illustrated by the results for steel Cr in Fig.3. No peaks were observed at any of the temperatures studied, the resistance change being a continuous decrease, though at a diminishing rate, as tempering proceeded. This general pattern of resistance change conforms to that for the removal of carbon from solid solution in martensite and is similar to that for plain carbon steels containing less than 1·05% carbon. The results at 120°C show that the process did not attain an end point before the onset of the third stage of tempering. A closer comparison of the results for steel Cr, Table II, and the previous data for plain carbon steels (Table II, ref. 4) reveals that under the same conditions of time and temperature the magnitude of *P* is almost exactly the same as that expected when tempering a 0·6% plain carbon steel. The variation of the initial rate of *P* with tempering temperature is also the same as that expected for a 0·6%C steel. Thus the effect on the time dependence of the kinetics of the first stage of tempering caused by adding 1·37%Cr to a 1·00% carbon steel appears to be equivalent to lowering the carbon content of the steel to 0·6%C.

A similar examination of the results for steel Mo in Table II reveals that the initial rate of *P* and its magnitude under various conditions of time and temperature conforms to that expected for a 1·0% plain carbon steel. This effective lowering of the carbon content of the alloy may be due directly to the influence of Mo in solution or simply result from the removal of carbon from solution by the undissolved carbides observed in the quenched specimens. In either event the effect is small and it is clear that Mo can have only a very slight influence on the form of the resistivity curve.

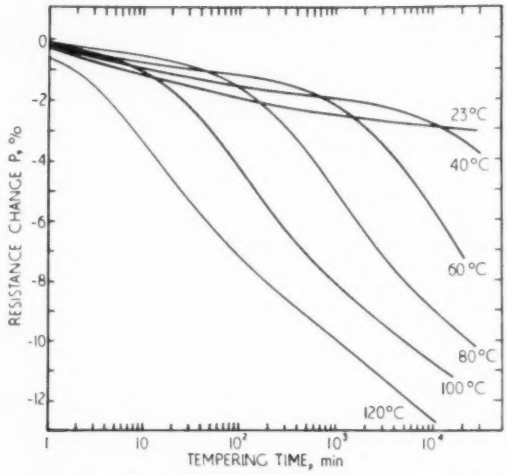
TABLE III Resistivity changes for steel 114, and Si and Ni steels

Steel	Tempering temperature, °C	Time to reach peak, min	Magnitude of P at peak, %	Time to cut $P=0$ axis, min
114	60	11	0·189	39
	40	78	0·278	640
	23	650	0·301	7400
Si	80	1	0·185	3·8
	60	16	0·910	150
	40	230	1·400	3250
	23	2500	1·620	41000
Ni	80	4	0·301	12
	60	45	0·700	410
	40	500	0·960	8500
	23	6400	1·293	125000

Steels Si, Ni, and 114

Electrical resistance changes measured during the tempering of steels Si, Ni, and 114 at various temperatures from room temperature to 100°C followed the form illustrated in Fig.4 for steel Si. At 100°C the tempering curves were similar in shape to those of steels Cr and Mo, but at lower temperatures the continuous decrease characteristic of the first stage of tempering was preceded by the resistance passing through a maximum, the value of P becoming positive during the early moments of tempering. At 23°C the value of P decreases slightly before becoming positive and passing through the peak. Both the intensity of the peak and its position along the time axis were increased as the tempering temperature was lowered, a behaviour which is consistent with that reported previously for the tempering of plain carbon steels containing more than 1·05%C.[4] A more detailed comparison is possible by comparing the height of the peaks, the tempering time at which the peak is reached, and the time at which the curve cuts the $P=0$ axis; these are listed for the three steels in Table III.

The intensity of the peaks observed during the tempering of steel 114 was consistently lower than those observed in plain carbon steels containing 1·50%, 1·38%, and 1·27%C, and a further effect of the lower carbon content of this steel is to be seen in the absence of a peak at 80°C. This is precisely the result expected for this steel on the basis of the earlier work on plain carbon steels. On the other hand, for steel Si, which has a carbon content only just a little lower than steel 114, the peak position and the time to cut the $P=0$ axis at any temperature are such as would be associated with a 1·43% plain carbon steel. Similarly the height of the peak at any given tempering temperature is of the order of that expected for a plain carbon steel containing almost the same carbon, 1·40%. For steel Ni, which contains 1·07%C, the positions of the peaks on the time axis again coincide with those for a higher carbon steel, 1·34%C, but in this case the peak heights are those expected for a much higher carbon steel, 1·45%C. Thus, the addition of either Si or Ni to high carbon steels enhances the tendency for the resistance to pass through a maximum at the lower tempering temperatures, Si affecting both the height and position of the peak to a corresponding degree, while Ni increases the peak height to a greater extent, in terms of the equivalent carbon content of a plain carbon steel, than it does the time at which the maximum is reached.



5 *Resistance changes during the isothermal tempering of steel* Mn

Steel Mn

The changes in resistance of steel Mn at temperatures above 100°C followed the same course as those observed for the other alloy steels, under the same conditions, as is shown by the results in Fig.5. The pattern of the changes at lower temperatures was more complex, however, since the rate of the resistance change first decelerated to a minimum value, after which it increased rapidly for a very short time and then diminished continuously. Hence the value of P, while it never became positive, passed through two closely adjacent points of inflextion associated with the minimum and maximum in the rate of the resistance changes. The times to reach the first point of inflextion and the value of P at this point are given in Table IV, together with the initial rates of P at the various temperatures. The points of inflexion occurred after longer tempering times, and at greater negative values of P, as the tempering temperature was lowered. In this respect the incidence of the first of the points of inflexion follows the same pattern as the incidence of the peaks in the resistance curves for steels Si and Ni (Table III).

The initial rate of the resistance changes was found to be greatest at 23°C and to diminish with increasing tempering temperature up to 80°C. The initial rate at 100°C was more rapid than at 80°C but still very much less than that expected for a 1·0%C steel. In magnitude it is comparable with the initial rate at 100°C of a 1·5% plain carbon steel (0·135% min^{-1}), which was considered to be diminished due to the effect of coherency strains on the electrical resistance of the martensite.[4] Thus the addition of 2·97%Mn to a 1·01%C steel caused it to exhibit a form of resistance change *v.* tempering time curve which does not readily fall into either of the two patterns established for plain carbon steels.

DISCUSSION

Influence of alloying elements on activation energy

The kinetics of the first stage process were analysed using a form of the Johnson–Mehl equation suggested

TABLE IV Resistance changes for Mn steel

Tempering temperature, °C	Initial rate, % min^{-1}	Time to reach point of inflexion, min	Magnitude of P at point of inflexion, %
100	0·114	...	...
80	0·064	4	0·352
60	0·137	40	0·976
40	0·212	500	1·850
23	0·246	10000	2·848

TABLE V Equivalent carbon contents

Steel	Carbon content, wt-%	Activation energy	Peak height	Time at $P=0$	Initial rate
Cr	1·00	0·54	...	...	0·6
Mo	1·07	0·96	...	...	1·0
Si	1·12	1·43	1·40	1·43	...
Ni	1·07	1·34	1·45	1·34	...
Mn	1·01	0·76	...	...	...

by Wert,[15] for the precipitation of carbide from supersaturated ferrite

$$\frac{\Delta C(t)}{C_0}=\frac{\Delta R}{R}=1-\exp\left[-\left(\frac{t}{\tau}\right)^n\right] \quad \ldots\ldots(2)$$

where $C(t)$ is the amount of carbon removed from solid solution after a time, t, C_0 the initial carbon content, n a constant independent of both temperature and C_0, and τ a time constant dependent on the diffusivity of the carbon atoms thus:

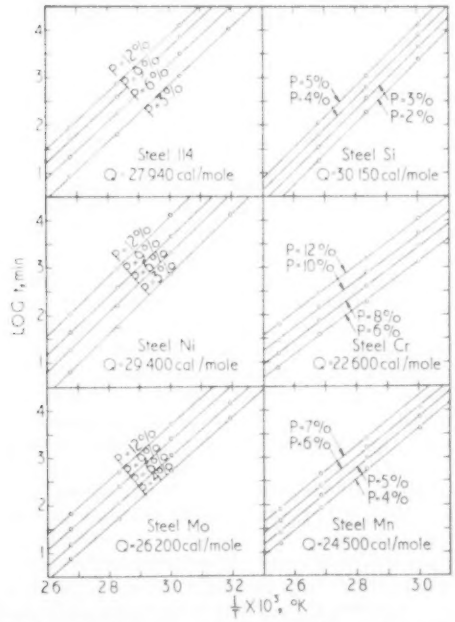
$$\tau=\frac{K}{D_0}\exp\frac{Q}{RT} \quad \ldots\ldots(3)$$

where Q is an energy of activation associated with the interstitial diffusion of carbon atoms, R is the gas constant and K a constant associated with nucleation. Substituting for τ in equation (2) gives:

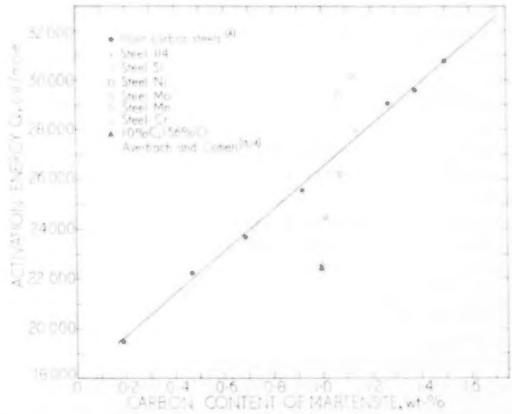
$$\frac{\Delta C(t)}{C_0}=\frac{\Delta R}{R}=1-\exp\left[\frac{-D_0}{K}t\exp\frac{-Q}{RT}\right]^n \quad \ldots\ldots(4)$$

Due to the somewhat erratic variation of initial rates with temperature (Tables II–IV) it was not possible to calculate any values for n. However, despite the occurrence of maxima and points of inflexion, the curves of resistivity change v. temperature for each of the steels all become parallel after some degree of tempering and remained so over a wide range of values of P. The activation energy for this part of the reaction was determined according to equation (4) by plotting the logarithm of the time to reach four different values of P against the reciprocal of the aboslute temperature as shown in Fig.6. To within the experimental limit, every plot of $1/T$ $v.$ log t gave a straight line, and further, over the ranges of P studied, the lines for any one steel were all parallel. Thus for each steel there is a unique activation energy for the process which can be calculated from the slope of the lines.

In Fig.7 the activation energies for the present six steels are compared with the results obtained previously for plain carbon steels. It is encouraging to find that the value for steel 114 conforms closely to the linear relationship between Q and carbon content established earlier. The values for the alloy steels, however, depart significantly from this straight line plot; steels Cr, Mn, and Mo are below while steels Si and Ni are above. This can be expressed in terms of the carbon contents of plain carbon steels having the same Q values as the nominally 1% carbon alloy steels and the result is that steels Cr, Mo, Si, Ni, and Mn correspond to plain carbon steels containing respectively 0·54, 0·96, 1·43, 1·34, and 0·76%C. A striking feature of these figures which can be seen from Table V is that for steels Si and Ni they agree precisely with the equivalent carbon contents deduced in terms of the peak height in the resistivity curve while for steels Cr and Mo, they resemble closely the plain carbon steel equivalents in terms of the initial rate of resistivity decay cited earlier as 0·6 and 1·0%. Also plotted in Fig.7 is Averbach and Cohen's value of 7480 cal/mole for a 1%C–1·56%Cr steel multiplied by the time exponent of the reaction to give the true activation energy as reasoned by Zener.[16] When thus corrected this earlier



6 *Relationship between log* t *and 1/*T *after various degrees of tempering for the six steels*



7 *Comparison of present results for activation energy (Fig.6) with those for plain carbon steels*

TABLE VI Comparison of lattice spacings in alloy and plain carbon martensites

Steel	C, wt-%	a, kX	c, kX	c/a
4·48%Ni*	1·06	2·849	2·989	1·049
Plain carbon†	1·06	2·847	2·984	1·048
1·96%Mn*	1·07	2·848	2·988	1·049
Plain carbon†	1·07	2·847	2·985	1·048
5·00%Mn*	0·81	2·856	2·953	1·034
Plain carbon†	0·81	2·850	2·955	1·037
4·97%Cr*	0·82	2·855	2·955	1·035
Plain carbon†	0·82	2·850	2·956	1·037

* Data from Nishyama[26]
† Calculated from results of Roberts[25]

estimate is seen to coincide almost exactly with the present value for a similar steel, showing a pronounced departure from the linear relationship for plain carbon steels.

Since the activation energy of the first stage of tempering remains constant at a value which is reached quite early in the process, the unique value obtained for each alloy steel is to be associated with the underlying mechanism, i.e. the diffusion of carbon in the martensite. This assumption has been challenged[17] on the basis of evidence that Q is very low in the initial period of the reaction and that this cannot be accounted for by a simple diffusion mechanism. It seems most probable, however, that during the initial moments of tempering, the kinetics of the reaction will be dominated by the process of carbide nucleation in a manner postulated by Kurdjumov and Lyssak[18] and, as already asserted,[19] the observation of anomalous kinetics during this period does not invalidate deductions based on the later more extended part of the reaction which consists mainly of the growth of carbide and concomitantly of a new low-carbon martensite.

The sites available for carbon atoms in body centred tetragonal martensite are limited to the octahedral interstices at the midpoints of the long cell edges, $00\frac{1}{2}$, and at the centres of the faces normal to these edges, $\frac{1}{2}\frac{1}{2}0$, all other octahedral sites being prohibited. The activation energy for the diffusion of carbon in martensite will thus be mainly associated with the energy barrier opposing the passage of the carbon atoms through the prohibited octahedral sites. Increasing the carbon content of plain carbon steels causes an increase in the axial ratio of the martensite and, as a consequence of the prohibited octahedral sites becoming even more unfavourable energetically, an increase in the energy barrier between occupied sites. This is reflected in Q increasing with carbon content according to the linear relationship already established.

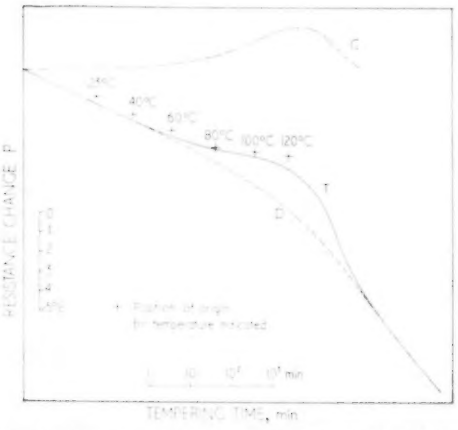
Now the influence of substitutional solutes on the tetragonality of martensite is slight (Table VI) so that it is unlikely that such elements would affect Q directly in the same way as carbon does. However, such elements will interact with carbon and may influence Q by this means. A formal view of the influence of alloying elements on Q is therefore to consider their effect on the thermodynamic activity coefficient, γ_c, of the dissolved carbon. Elements which raise γ_c would be expected to increase Q to a value characteristic of a steel of higher carbon content and conversely, where γ_c is lowered, Q should be reduced. Although the effects of alloying elements on the activity coefficient for carbon in martensite have not been measured, it is to be expected[20] that the carbide forming elements (Mo, Cr, and Mn in the present case) would reduce γ_c, as has been confirmed for Mn in austenite[21] and Cr in liquid iron.[22] Elements such as Ni and Si, on the other hand, which in solution in iron promote the formation of graphite rather than a carbide phase, can be assumed to raise γ_c in martensite as they are known to do in austenite.[21,23]

It is of interest to consider the relative strengths of the influence of the alloying elements on Q. From Fig.7 we see that 1·78 wt-% (3·34 at-%) Si raises Q from 27500 to 31500 cal/mole whereas 5·14 wt-% (4·91 at-%) Ni raises Q by a smaller amount, from 27100 to 29400 cal/mole. Thus Si is the more potent, 1 at-% of the element raising Q by 1200 cal/mole compared with 470 cal/mole for 1 at-%Ni. The inference that Si is more effective than Ni in raising γ_c, though it cannot be tested directly for martensite, is consistent with the data of Smith[21,23] for austenite. Considering the effects of the carbide forming elements in a similar manner, 1 at-% of Cr, Mo, and Mn lower Q by 2650, 1530, and 960 cal/mole respectively. There is some uncertainty in the value for Mn due to the presence of Si and Cr in this steel, though these elements have opposite effects on Q_c and seem to be in about the right proportion for mutual cancellation; also the value for Mo should probably be higher, taking account of the presence of a little undissolved carbide in this steel, whilst the effect of Cr is perhaps exaggerated slightly by the presence of some Mo in steel Cr. Despite these restrictions on the precise interpretation of the results, it is clear that Cr and Mo lower Q by a roughly equal amount which is about double that caused by Mn. Again, if the inference is accepted that γ_c is reduced about equally by Mo and Cr and to about half the extent by Mn, the results agree broadly with the accepted carbide forming propensities of these elements, Mo and Cr being much stronger carbide formers than Mn.

Influence of alloying elements on the form of the resistance changes

Since the activation energy for an individual steel is unique throughout most of the reaction at temperatures from 23° to 100°C, it would seem reasonable to infer that the mechanism of the tempering process remains the same over this range of temperature. The variation in the form of the observed changes of resistance must then be simply a manifestation of the effect of temperature on the reaction rate, which in turn affects the point to which the reaction has progressed within the first minute. This influence was tested by attempting to superimpose the curves of P *v.* log t, obtained for a steel at various temperatures by an appropriate shift of the origin. The test was successful and is illustrated by the common curve T in Fig.8 for the results of steel Mn. In this plot the progress of the resistance changes observed at any temperature is given by that portion of curve T on the right-hand side of the respective origin. Clearly the horizontal displacement of the tempering curves along the log-time scale implies a variation of the time constant τ with temperature, and the closeness with which the curves could be fitted to the common curve T, as in Fig.8, confirms the validity of equation (3), which was used to calculate the activation energies.

It also follows from equation (3) that a variation in τ, and hence a shift of the tempering curves along the



8 *Contributions of the coherency effect* (C) *and the depletion of carbon in solution* (D) *to the total observed resistance change* (T) *during the tempering of steel* Mn

log-time scale, is to be expected by varying the activation energy Q at constant temperature. This raises the question whether the observation of positive maxima in the tempering curves of any of the steels is dependent at least in part on the activation energy of the process. An attempt at superimposing the curves of P *v.* log t obtained previously[4] for plain carbon steels containing 1·27%, 1·38%, and 1·50%C together with those for steels Si, Ni, and 114 without any normalizing treatment, proved unsuccessful at all temperatures. If the curves were to be normalized using a simple multiplication factor, this would change the magnitude of P at any given tempering time, but neither the position of the peaks along the time axis nor the time at which the curves cut the $P=0$ axis would be affected (*see* Fig.1, ref.4). The effect of Q on τ may thus be examined according to equation (3) by plotting the logarithm of the time to reach either the peak or the $P=0$ axis, at constant tempering temperature, against the activation energy of the process for the various steels. Since log t at $P=0$ could be read off more accurately from the curves than log t at the peak, the former values were used for this examination. The plot at 80°C yielded a straight line from the slope of which T was calculated to be 355°K or 82°C, but at lower temperatures the data were so scattered that no straight lines could be drawn with any confidence. Hence, at tempering temperatures when the peaks are very small and tending to disappear, the displacement of the curves along the log t scale is controlled almost completely by the activation energy. The maxima observed at the lower tempering temperatures result from a poistive change in resistance, which is superimposed on the normal decrease associated with the removal of carbon atoms from solid solution in the martensite. It is only the latter negative component which can truly be equated to $\Delta C(t)/C_0$ in equation (2). Nevertheless, since the magnitude of the positive component is also some function of the removal of carbon atoms from solid solution, the point at which the values of P pass through a peak, or cut the $P=0$ axis, will depend at least qualitatively on the activation energy of the process.

On the basis of the above reasoning it may be concluded that in steels Cr and Mo the primary influence of the alloying elements is to so lower the activation energy that no maxima in the value of P can be observed after the first minute of tempering in the temperature range 23–100°C. There is thus a close correlation both in terms of the activation energies of the process and also in the magnitude of P under any given tempering conditions between these steels and plain carbon steels containing 0·55–0·6% and 0·96–1·0%C respectively (Table V). There is again a close correlation between activation energies and the times at which $P=0$ between steels Si and Ni and plain carbon steels containing 1·43% and 1·34%C, respectively, indicating that the occurrence of peaks in the resistance curves for these alloy steels is due in part to the effects of Si and Ni on the activation energy of the process. However, the peak heights in steel Si are too low for a 1·43%C steel, while those for steel Ni are higher than would be expected in a 1·34%C steel. Ni must thus enhance, and Si diminish, the positive component of resistance which is superimposed on the decrease due to the removal of carbon from solid solution. The effect of Mn is to lower the value of the activation energy to that for a plain carbon steel containing 0·76%C, when no peaks would be expected after the first minute of tempering. Even so from the form of the resistance changes, which pass through two points of inflexion (Fig.5), the influence of the positive component of resistance must extend significantly over the early stages of the process. If the resistivity changes due simply to the removal of carbon atoms from solid solution in the martensite be assumed to follow the same course as the dilatation which accompanies tempering,[1] then it can be described conjecturally by the broken line D in Fig.8. When the resistance changes due to this effect alone are subtracted from the measured values, curve T, a positive component of resistance change, C, results. The curve C differs from that deduced for the positive component in plain carbon steels of high carbon content (Fig.5, ref.4) in that quite a considerable decrease in D must occur before there is any detectable increase in C.

The positive component of resistance change which causes the value of P to pass through a maximum, or through a point of inflexion, before decreasing to follow the normal kinetics of the first stage of tempering has been attributed to the strains associated with the coherent precipitation of ϵ-carbide,[4] based on the suggestion by Jack[24] that during precipitation the $(10\bar{1}1)$ plane of ϵ-carbide is parallel and coherent with the (101) of the martensite. Due to the variation of the lattice spacings of martensite with carbon content[25] the degree of misfit between these planes of the matrix and precipitate is negligible in a 1·50%C steel, 0·97% in a 0·92%C steel, and 2·17% in a 0·19%C steel. In lower carbon steels where the misfit is greatest, the strains will become excessive soon after the beginning of tempering, causing the particle to break away from the matrix. In this case the positive component of P will be small and no peaks will be observed, but the initial rate of the resistance changes may be affected. In high carbon steels where the misfit is small, the particles will not break away so early and the value of P may become positive and pass through a peak, the height of which will vary inversely with the degree of the misfit between the matching planes. According to this picture the present results would suggest the degree of misfit is increased by Si

and decreased with the addition of Ni to plain carbon steels. Similarly, the degree of misfit in steel Mn must be very small since quite a large amount of carbon is removed from solid solution before the strains are sufficient to influence the observed change in electrical resistance.

The influence of Ni, Mn, and Cr on the lattice spacings of carbon martensites can be deduced from the data reported by Nishyama[26] for alloy steels, which is given in Table V together with the data for plain carbon steels of the same carbon content calculated from the results of Roberts.[25] It is seen that Ni does in fact increase the lattice spacings of martensite and thus decreases the degree of misfit of the (101) plane of the martensite relative to the $(10\bar{1}1)$ plane of ϵ-carbide in steel Ni. The influence of Mn is more than double that of Ni, per wt-%, and hence the presence of 2·96%Mn in steel Mn should cause the lattice spacings to be increased even more markedly than in steel Ni. The misfit between the matching planes, and hence also the coherency strains, will thus be very small in this steel, as they are required to be by the present argument. The effect of Cr on the lattice spacings is about the same as that of Mn. Since only 1·37% of this element is present in steel Cr, however, the lattice strains may well not be decreased sufficiently to counteract the very strong influence of Cr on the activation energy and hence no points of inflexion would be expected in the change of P with tempering time. Even so, the initial rates and magnitude of P correspond with those for a slightly higher carbon steel (0·6%C) than does the activation energy (0·55%C). The effect of Si on the lattice spacings of martensite has not been reported, but it is known to be the only one of the present alloying elements which causes the lattice parameter of α-iron to be decreased.[27] If its effect in martensite is consistent with this trend, the lattice spacings on steel Si should be decreased by the addition of 1·78%Si causing the required increase in the strains associated with the coherent precipitation of ϵ-carbide. Conversely from its considerable effect on the lattice spacings of α-iron[28] even a small amount of Mo should decrease the coherency strains. This is also consistent with the present results, since the initial rates and magnitude of P compare with those for a 1·0%C steel, while the activation energy is similar to that for a 0·96%C steel.

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Protection of open-hearth furnace roofs by an auxiliary jet

J. V. Edwards

SYNOPSIS

In many OH furnaces preferential wear occurs in an extensive area at the extreme back of the roof, including the area above the taphole. The rate of erosion in this area can be reduced by use of a jet situated near the junction of the furnace roof with the back wall, midway along the furnace length and firing towards the bath. Under some conditions, this arrangement increases the rate of wear nearer the crown, and in a small area around the jet, but by selection of the correct flow rate and the use of a compound instead of a simple jet, these difficulties have been overcome. A cheap and simple installation, firing steam, has been developed and installed on two 200-ton furnaces.

1869

INTRODUCTION

THE GENERAL FEATURES of the roof wear pattern in open-hearth furnaces heated by a single burner are consistent almost without exception, although the detail may differ at various plants. Target areas occur adjacent to the back and front skewbacks. The former is usually the more critical area, sometimes to such an extent that the selective wear at the front is hardly apparent before the roof is incapable of further service.

Tests on cold models have explained these phenomena in terms of the flow pattern of the furnace gases.[1] Gases flowing up the back wall, and to a lesser extent up the front wall, transfer iron oxide to the adjacent parts of the roof, which are then rapidly attacked in the prevailing reducing atmosphere.

Sometimes the target area is not very extensive, and in such cases it may be practicable to relieve the condition by applying an air curtain against the hot face of the refractory.[2] However, at the Abbey Works of the Steel Company of Wales Ltd, the critical area adjacent to the back wall extends almost the whole length of the furnace. In such a case a protective curtain would require impracticably large quantities of air and the installation would be cumbersome. Research has therefore been directed towards opposing the upward flow of gases by use of a jet firing towards the bath from a position which is flush with the inside of the roof when the latter is new. The jet is sited near the back skewback and is just sufficiently inclined to the vertical to avoid striking the back bank.

THE FURNACE

The furnace is a twin uptake, 200-ton capacity OH furnace, firing a maximum of 500 gallons of fuel oil per hour. The internal dimensions are shown in Fig.1. The shop employs a standard roof design with a 6-ft zebra strip adjacent to the back springing. This consists of top-quality silica alternating with chrome–magnesite. There is a 2-ft wide strip of top-quality silica adjacent to the zebra, and this strip is usually called the 'zebra-plus'. Apart from a 3-ft zebra strip adjacent to the front wall, the rest of the roof is constructed in silica, which although inferior to the silica in the zebra-plus, is still in the super-duty class.

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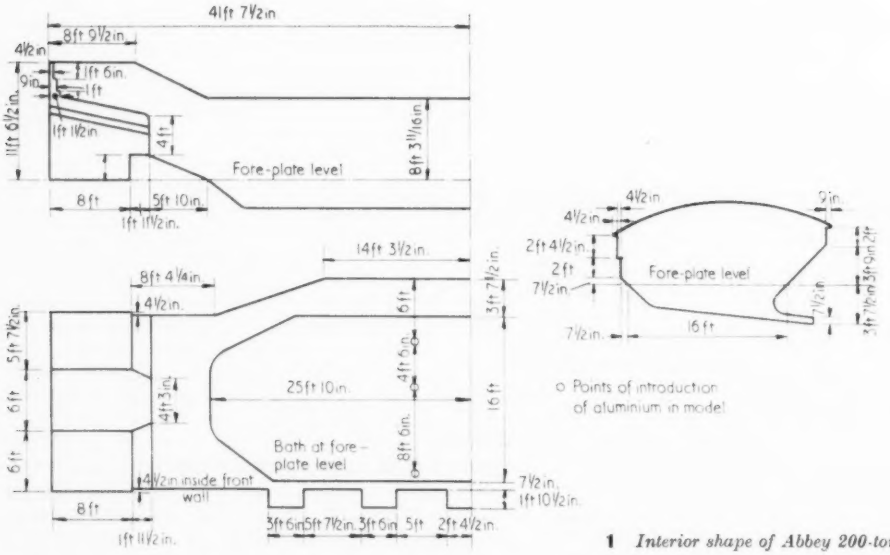
EXPERIMENTAL TECHNIQUES WITH A COLD MODEL

A $\frac{1}{24}$ scale model of the furnace constructed in perspex was used for the laboratory tests. A solid plane surface was used to simulate the slag surface, and the operating fluid was air.

Preliminary visual examination of the flow pattern and the way it was affected by a jet at various points was made by introducing balsa dust into the model and illuminating with an arc lamp. An aluminium deposition technique based on that developed by Leys and Leigh[1] was then used to obtain quantitative results. This method utilizes a black roof coated with a thin layer of oil. Aluminium powder was introduced into the model at three points, the locations of which are shown in Fig.1. In each test, $\frac{1}{8}$ g of aluminium was introduced at each of these points, and released about $\frac{1}{2}$ in. (1 ft full scale) above the slag level, preliminary tests having shown this to produce a deposit on the roof which was consistent with the observed pattern of wear on the actual furnace (i.e. after weighting the pattern for furnace reversal, the regions of heavier aluminium deposit on the model correspond with regions of more severe erosion on the roof). The weight of deposit on the back 2 in. of the main roof was obtained by washing into a filter paper with carbon tetrachloride, drying and then weighing. Similarity conditions are discussed in the Appendix.

VISUAL EXAMINATION OF THE FLOW PATTERN

These tests were intended to determine whether auxiliary jets could cause desirable changes in the flow



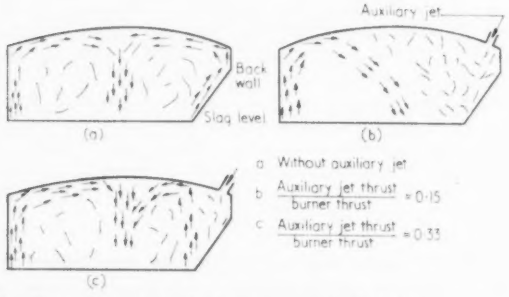
1 *Interior shape of Abbey 200-ton OH furnace*

pattern and if so, what would be the best place to introduce them, how many would be required, and what quantity of steam would be necessary to operate them.

The flow pattern inside the model was qualitatively consistent with that observed in similar systems by other workers.[3] The particular feature of interest was the flow up the back wall towards the roof, which originated between $\frac{1}{3}$ and $\frac{1}{2}$ the furnace length from the firing end, and continued to the waste-gas end of the furnace.

Observation established that a jet placed near the junction of the roof with the back wall and firing towards the bath would modify the flow up the back wall. It was also noted that if the flow rate through the jet were high enough, then its effect extended downstream of itself as far as the furnace downtakes. This was particularly interesting, since it implied that a simple installation of one jet, sited midway along the furnace would be sufficient and thus no special arrangement would be necessary to accommodate furnace reversals. With such a jet in this position on the model, its effect was examined as the flow rate was increased from zero upwards.

With the burner firing at $7\frac{1}{2}°$ towards the hearth and parallel to the furnace axis, the following effects were observed.



2 *Flow pattern in centre transverse vertical plane*

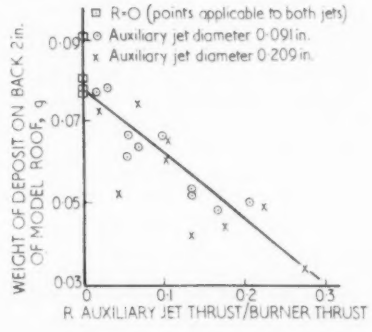
With low flow rates through the auxiliary jet there was no change in the basic nature of the flow pattern, but the flow up the back wall seemed slower. When the auxiliary jet thrust was about 15% of the burner thrust there was no longer a distinct flow up the back wall in the region near the jet. When the auxiliary jet thrust was further increased to about 33% of the burner thrust, there was no definite flow up the back wall anywhere downstream of the jet, while near the jet itself the gas stream had reversed its usual direction and now flowed towards the bath. However, a secondary flow from hearth to roof was now present, and this met the roof at about 6 ft (full scale) from the junction of the roof with the back wall. These effects are illustrated in Fig.2.

It was concluded, therefore, that whereas this device could be used to protect the extreme back of the roof, the secondary flow would increase wear nearer the crown if the operating thrust were too high. This, in fact, occurred during the first furnace trial (*see* below). With other burner directions the same effects occurred but at different levels of auxiliary jet thrust.

ALUMINIUM DEPOSITION TESTS

Effect of jet diameter

In the derivation of the similarity criteria for OH furnace models it is implicitly assumed that the jet diameter is so small in model and furnace that geo-

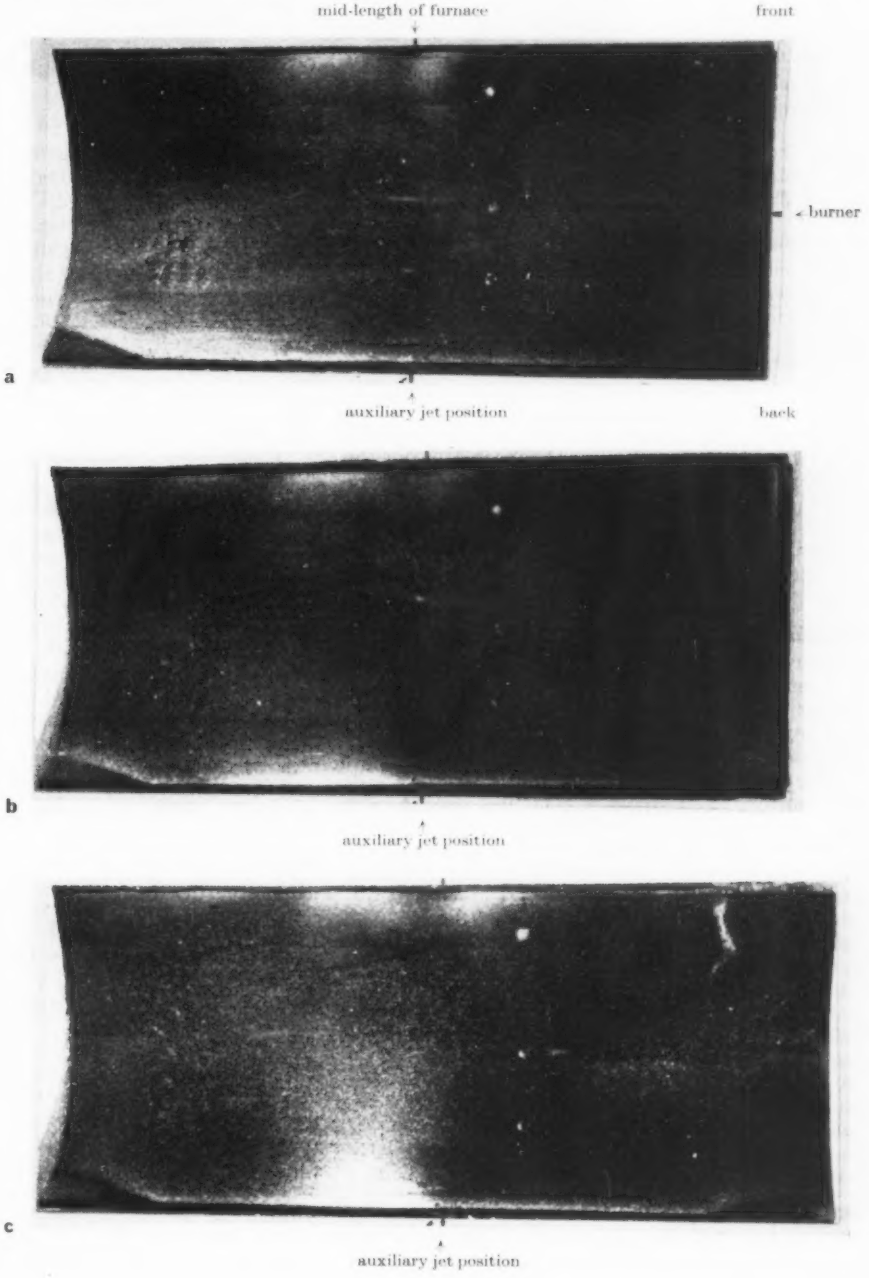


3 *Effect of auxiliary jet on weight of deposit*

metrical similarity in this respect is unimportant. There was some doubt as to the validity of this assumption in the case of the auxiliary jet since in the model the thickness of the stream it was required to repel (i.e. the gas stream up the back wall) was only of the order of five times the diameter of the smallest jet that could be used to obtain a suitable thrust from the blower available. In contrast, in the furnace, this layer would be of the order of 50 times the auxiliary jet diameter. Tests were therefore carried out with jets of diameters 0·091 in. and 0·209 in. Figure 3 shows the variation of weight of deposit with jet thrust for these two jets. Statistical examination showed no significant difference between the jets. This verified selection of the thrust as the criterion for comparing model and furnace, and indicated that, within the range it was possible to test, the diameter of the jet was not important.

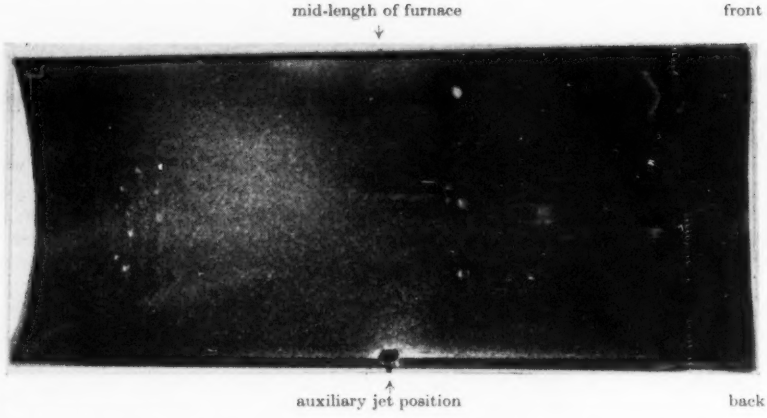
Variation of deposition pattern with jet thrust

The patterns of aluminium deposit verified the conclusions from the visual test, i.e. deposit on the back of the roof diminished as the auxiliary jet thrust increased, but at higher thrusts the deposit increased



a no auxiliary jet
b auxiliary jet thrust/burner thrust = 0·15
c auxiliary jet thrust/burner thrust = 0·5
(the brighter regions are regions of heavier deposit)

4 *Effect of auxiliary jet on deposition pattern on main roof (between knuckles)*



auxiliary jet thrust/burner thrust = 0·5 (*cf.* Fig.4*c*) (the brighter regions are regions of heavier deposit)

5 *Deposition pattern with compound auxiliary jet*

nearer the crown. It was also observed that a small area of heavy deposit remained in a region surrounding the jet. These effects are illustrated in Fig.4.

Jets with inspiration gaps

The small area of heavy deposit remains around the jet because whereas the jet momentum opposes the upward flow in the furnace, as intended, it also possesses the normal properties of entrainment. The problem, therefore, was to retain the jet momentum but avoid the entrainment of furnace gases near the jet nozzle. It was thought that if there were a gap near the jet which vented the furnace to atmosphere, then the jet could to some extent entrain atmospheric air instead of destructive furnace gases.

A gap in the roof surrounding the jet produced no obvious change in the deposition pattern. Gaps immediately behind the jet, between the roof and back wall, merely displaced the local deposit towards the crown.

Compound jets

It seemed possible that if the simple jet were replaced by a number of jets situated very closely together, without changing the total thrust, then the entrainment property might be partially expended in mutual interaction.

Using two jets, each of diameter 0·091 in., with their centres 0·2 in. apart (4·8 in. full scale) in the direction of the furnace length, the deposit around the jet was not eliminated but its extent was reduced. When four jets (each of diameter 0·05 in.), arranged linearly with centre separations of 0·1 in. (2·4 in. full scale) were used the results were much better. The pattern of deposit around the jet was now much improved (*see* Fig.5).

A compound of four jets, each of diameter 0·05 in., arranged with their centres at the corners of a square of side 0·1 in. was less effective than the linear four arrangement.

A compound of eight jets, each of diameter 0·05 in., arranged in two rows of four in the direction of the furnace length with centre separations and row separations of 0·1 in. (2·4 in. full scale) was as effective as, but no better than, the linear four arrangement.

FURNACE TRIALS

Following the laboratory experiments with simple jets, a water-cooled jet was installed in one furnace. The jet was fitted with a convergent nozzle of exit diameter $\frac{3}{8}$ in. firing 400 lb of steam per hour.

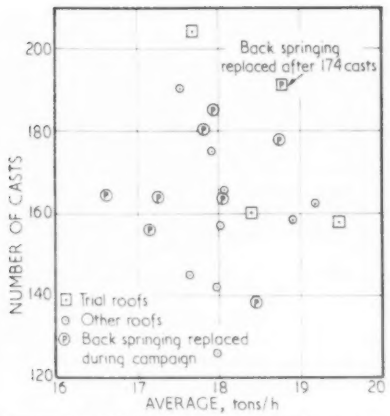
At an early stage a gouge was observed to be forming near the jet, but since this was only about 18 in. long it was not regarded as serious. However, after little more than half the normal furnace life the campaign had to be concluded because of the condition of the roof. The main features of interest were: (*a*) the least worn parts of the roof were the back zebra (normally the worst worn part) and the adjacent zebra-plus, and (*b*) a gutter, 2 ft wide and extending almost the whole length of the furnace, had formed adjacent to the zebra-plus.

It was obvious that the selected steam flow rate through the auxiliary jet was too high. However, this trial confirmed that a jet used in this way did protect the extreme back of the roof, and it was decided to have another trial on the same furnace. Because of the experience of the first trial, the top-quality silica of the zebra-plus was extended a further 2 ft and the steam flow rate through the auxiliary jet was reduced to 250 lb/h. After about $\frac{2}{3}$ of the normal roof life this campaign was concluded because an area about 6 ft long × 2 ft wide, surrounding the jet, had worn to such an extent that the roof began to sag. Apart from this local area, the roof was of remarkably uniform thickness.

It was now obvious that although the gouge near the crown, which occurred in the first trial, could be eliminated, the small region of wear around the jet was still important. Two courses were now possible: (*a*) to use the jet as before and patch this local area halfway through the campaign, or (*b*) to make further tests on the model to investigate possible means of eliminating this erosion near the jet.

The latter course was adopted and at this stage the tests with inspiration gaps and compound jets were carried out on the model.

Following these tests it was decided to carry out furnace trials with a compound of four jets arranged linearly. In the first trial the steam was passed through four recrystallized alumina tubes whose centre separations were 3 in. These tubes failed after $7\frac{1}{2}$ weeks, and the steam 'ratholed' the adjacent bricks. A patch of 20 bricks was installed and the campaign continued without the use of the jets. After 174 casts the whole of the back springing was replaced, the campaign being concluded after a further 17 casts. The average



6 *Performance of 200-ton OH furnace roofs during period of trials*

production rate during this campaign was 18·77 tons/h. At the time of repair the roof was capable of further service and would not normally have been patched were it not for abnormal furnace repair bunching conditions occurring on the shop at this time.

For the following campaign, a water-cooled box containing four jets was built into the roof in place of two bricks, but this failed after three weeks. This campaign was concluded after 204 casts, the average production rate during the campaign being 17·67 tons/h.

The design of the water-cooling arrangement was modified for the next trial, which was concluded after 158 casts during which the average production rate was 19·47 tons/h. This revised installation survived the campaign, but because of modifications being carried out on the steam line it was in operation for only 5½ weeks. This result was particularly encouraging since the roof was marked before the jets were brought into use, and under normal circumstances would almost certainly have required replacement of the back springing before the conclusion of the campaign.

A further trial was concluded after 160 casts during which the production rate averaged 18·40 tons/h.

Figure 6 compares the four trials using compound jets with campaigns of similar furnaces on the shop from the beginning of the period of these trials until the conclusion of the penultimate trial.

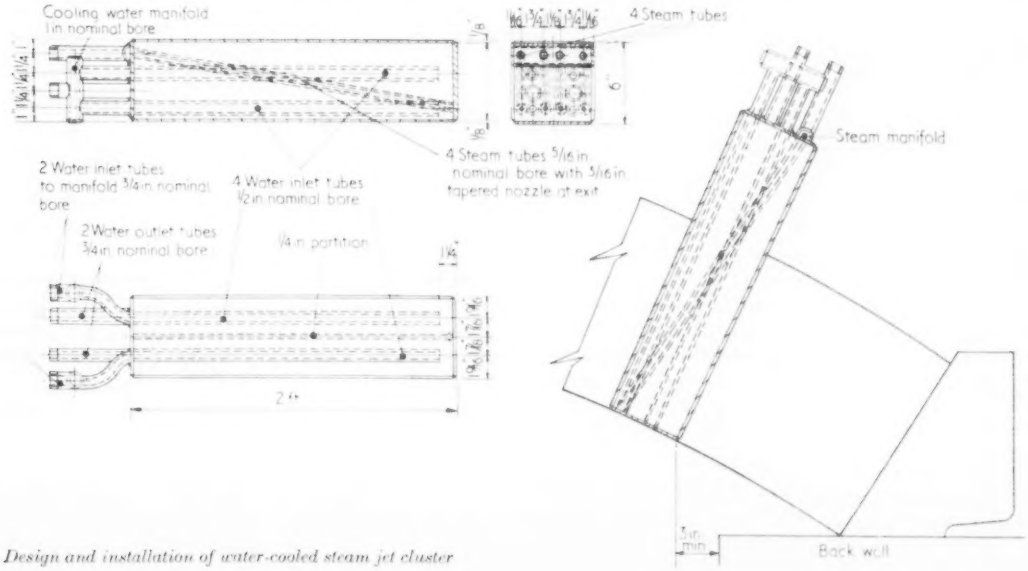
While it is realized that the results are few in number, they are presented at this stage because no further results with this roof design will be available, as basic roofs will be used on all future builds on this shop. However, the results to date have supported the indications from the model that jets used in this way can protect the extreme back of the roof.

It will be seen that all the trial furnaces were capable of a reasonable life by shop standard without replacing the back springing, while about half the furnaces without auxiliary jets required this large repair. The results were therefore regarded as encouraging.

Consequently, water-cooled jet clusters similar to that used in the last trial have now been permanently installed on two of the 200-ton furnaces on Abbey melting shop so that results can be obtained from a large number of campaigns with basic roofs. The design of the water-cooled jet cluster and the mode of installation in the roof, in place of two bricks, is shown in Fig.7.

ACKNOWLEDGMENTS

The author is indebted to Dr A. J. Kesterton, Superintendent–steel plants, who first suggested using jets in this way, and to the personnel at Abbey Melting Shop for their co-operation. Mr A. J. K. Honeyman, formerly Superintendent of Research (Steel Division), gave advice and encouragement, and the staff of the Aerodynamics Laboratory assisted with the experimental work. He also wishes to thank the Directors of the Steel Company of Wales Ltd, for permission to publish this paper.


Cooling water manifold 1in nominal bore
4 Steam tubes
4 Steam tubes 5/16 in nominal bore with 5/16 in tapered nozzle at exit
Steam manifold
2 Water inlet tubes to manifold 3/4in nominal bore
4 Water inlet tubes 1/2in nominal bore
2 Water outlet tubes 3/4in nominal bore
1/4in partition
Back wall

7 *Design and installation of water-cooled steam jet cluster*

APPENDIX

Similarity considerations

The model was operated using the similarity criterion suggested by Leys and Leigh, namely:

$$\left\{\frac{L\sqrt{\overline{\rho g}}}{m}\right\}\text{model} = \left\{\frac{L\sqrt{\overline{\rho g}}}{m}\right\}\text{furnace} \quad \ldots\ldots(1)$$

where L is a characteristic dimension, ρ the density of the gases at the end of the flame, g the burner thrust, and m the mass flow rate of the combustion air.

To include the auxiliary jet we require also,

$$\left\{\frac{L\sqrt{\overline{\rho_a g_a}}}{m}\right\}\text{model} = \left\{\frac{L\sqrt{\overline{\rho_a g_a}}}{m}\right\}\text{furnace} \quad \ldots\ldots(2)$$

where ρ_a is the gas density at the end of the auxiliary jet and g_a the auxiliary jet thrust. Since only air is used in the model, $\rho_a = \rho$. This is probably roughly true for the furnace, since combustion is well advanced halfway along the furnace, where the auxiliary jet is entraining the furnace gases. This approximation simplifies (2) to

$$\left\{\frac{g_a}{g}\right\}\text{model} = \left\{\frac{g_a}{g}\right\}\text{furnace} \quad \ldots\ldots(3)$$

The Reynolds' number in the downtake of the model was approximately half that in the downtake of the furnace, but since the flow was still turbulent, this deviation is not serious.

The burner nozzle diameter in the model was 0·418 in., which is 80% larger than that required by the more complete similarity criteria derived by Thring and Newby,[4] and later by Thurlow.[5] Examination of the results of Hinze as arranged by Thring and Newby suggests that the section at which a given mass of combustion air was entrained into the fuel jet would be displaced by approximately ½ in. (1 ft full scale) as a result of this deviation in jet diameter. The quantity of entrained air would deviate by about 4% at the furnace mid-length, and this deviation would diminish as the distance from the burner nozzle increased. We are principally interested in the flow downstream of the furnace mid-length in the present case, and thus it was considered preferable to tolerate these discrepancies rather than to reduce the Reynolds' number further.

Considering the criteria for similarity of particle path, it was found that the general equation of motion did not yield reasonable values for the particle size and density required in the model, and also required velocities based on the Froude criterion, which in this case involved reduction of the Reynolds' number to about 1/6 its value in the furnace. Leys and Leigh, and later Granville and Sigalla,[6] showed that particle flight could be modelled with reasonable particle requirements if motion is assumed to be entirely in the range where Stokes' drag law applies, but again the velocities must be based on the Froude criterion.

In the present case, we were not completely satisfied that the flow pattern remained similar when the Reynolds' number was reduced to achieve Froude similarity, and so the deposition tests were carried out with the same flow rates as the visual tests. The particle size range and points of introduction in the model were selected to produce a deposition pattern consistent with the characteristic wear pattern of the furnace roof. The same batch of aluminium, and the same points of introduction were then used throughout the series of tests.

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A comprehensive examination of samples of iron containing aluminous inclusions

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SYNOPSIS

A comprehensive investigation has been made of inclusions in several ingots of the aluminium deoxidation series of Sloman and Evans, embracing metallographic studies and examinations after isolation in extraction replicas, by optical and electron microscopy and electron and X-ray diffraction. The results of the investigation have confirmed the general findings of previous investigators and have revealed additional information concerning the morphology and composition of the inclusions. In particular the previously encountered anomaly concerning the occurrence of magnetite in the inclusions of the oxygen-rich ingots has been elucidated. These inclusions consist of a wüstite matrix containing hercynite either in the form of large idiomorphic crystals, dendritic particles, or separate particles. Magnetite is also present in the wüstite at or near the surface of the inclusions in the form of separate particles and/or semi-continuous layers. The manner of formation of the hercynite and magnetite is discussed.

Use was made during the examination of a new technique for the study of separate constituents within individual inclusions. One of the constituents present in the inclusions was partially dissolved chemically and the remaining less soluble constituents were isolated in extraction replicas, examined in detail by electron microscopy, and identified by 'selected area' electron diffraction. 1815

INTRODUCTION

THE PREPARATION and extensive examination of pure iron ingots containing aluminous inclusions has been described by Sloman and Evans[1] and a subsequent microscopic examination was undertaken by Lismer and Pickering.[2] These investigations showed that the form and composition of the inclusions depended largely on the relative amounts of oxygen and aluminium present in the ingots. The main types of inclusion observed could be grouped as follows:

(i) in the aluminium-rich ingots, clusters of small particles (Fig.1, A1 and B1) of alumina (α–Al_2O_3)
(ii) in the intermediate ingots, elongated particles (Fig.1, C1 and D1) which were probably a form of hercynite ($FeO.Al_2O_3$) and
(iii) in the oxygen-rich ingots, wüstite (FeO) globules containing the spinel hercynite either as fine particles (Fig.1, E1) or large idiomorphic crystals (Fig.1, F1). Metallic particles were also sometimes observed in these inclusions.

The constituents were identified both by normal metallographic methods and by X-ray diffraction studies on alcohol–iodine bulk extraction residues. There was good agreement between the identifications made by the two methods except for the oxygen-rich ingots when magnetite was found as a major phase by X-ray diffraction but could not be positively detected by metallographic methods.

The present paper describes further studies on some of these ingots. In particular, inclusions have been isolated from polished sections by an extraction replica method,[3] and comprehensively examined by optical and electron microscopy and electron and X-ray diffraction,[4] thus revealing additional information concerning the morphology and composition of the inclusions. The oxygen and aluminium contents of the ingots given in Table I are taken from the paper of Sloman and Evans.[1]

EXAMINATION

Following a metallographic examination of ingots *E*, *K*, *J*, *P*, *M*, *F*, and *N*, ingots *E*, *J*, and *F* were selected for a detailed comprehensive examination because together they contained all the main types of inclusion. The inclusions in these selected ingots were isolated in extraction replicas[3] using 10% nital as etchant. The etch times were: about 30 s for the small particles in ingot *E*, 1 min for the elongated particles of ingot *J*, and 3 min for the large globular particles of ingot *F*. Some further extraction replicas[3] were obtained using 10% iodine–alcohol as etchant and slightly longer etch times. The resulting extraction replicas were examined by transmission optical microscopy and then by electron microscopy and electron diffraction in a Metropolitan-Vickers type EM3 electron microscope. Similar extraction replicas were rolled up to form small cylindrical specimens for examination by X-ray diffraction.[4]

Some additional studies were made on the inclusions of ingot *F*. First, a modified extraction replica technique was used which enabled separate constituents within individual inclusions to be isolated and then examined by electron microscopy and identified by electron diffraction. The details of this technique are given later. Extraction replicas obtained in this manner were also examined by X-ray diffraction. Second, the inclusions in a polished section were examined by optical microscopy both before and after selective reduction caused by heating for ½ h at 800°C in dry hydrogen.

RESULTS

Metallographic

The results of the metallographic examination were in reasonable agreement with the results similarly obtained by previous investigators,[1,2] including the failure to locate the magnetite shown to be present in the inclusions of the oxygen-rich ingots by the X-ray diffraction studies. However, at the edges of many of these latter inclusions a continuous grey zone, lighter in colour than the main wüstite phase, was observed which extended in some instances appreciable distances inwards. Zones of this nature had also been observed by Sloman and Evans.[1]

Optical and electron microscopy

The isolation of characteristic inclusions by the extraction replica method and their subsequent examination is illustrated by Fig.1. Micrographs in the same columns are from identical areas and hence the appearance of individual particles at different stages of examination can be compared.

The characteristic particles in ingot *E* (Fig.1, A1 and B1) were transparent to light (Fig.1, A2 and B2) and consisted of stringers or dumb-bells (Fig.1, A3 and B3, and Fig.2*a*). A detailed examination of numerous extraction replicas established that although this was the most common type of particle in ingot *E*, irregular particles with rough edges (Fig.2*b*) and on rare occasions angular particles (Fig.2*c*) also occurred.

The elongated particles characteristic of ingot *J* (Fig.1, C1 and D1) were in general transparent to light (Fig.1, C2 and D2) and occurred in the form of irregularly shaped rods (Fig.1, C3 and D3) but since only a small number of these particles were present in ingot *J* (described later), a comprehensive survey was not made.

The complex nature of the inclusions of ingot *F* (Fig.1, E1 and F1) was not revealed by either the transmission optical microscope (Fig.1, E2 and F2) or the transmission electron microscope (Fig.1, E3 and F3) studies. A survey showed that about half the inclusions in this ingot were approximately spherical in form with either smooth (Fig.3*a*) or slightly rough surfaces. Others were either spherical with somewhat flattened faces (Fig.3*b*), angular in a regular manner (Fig.3*c*), or partly spherical and partly angular (Fig.3*d*). In addition, some were characterized by 'missing' portions (Fig.3*e*). On rare occasions instead

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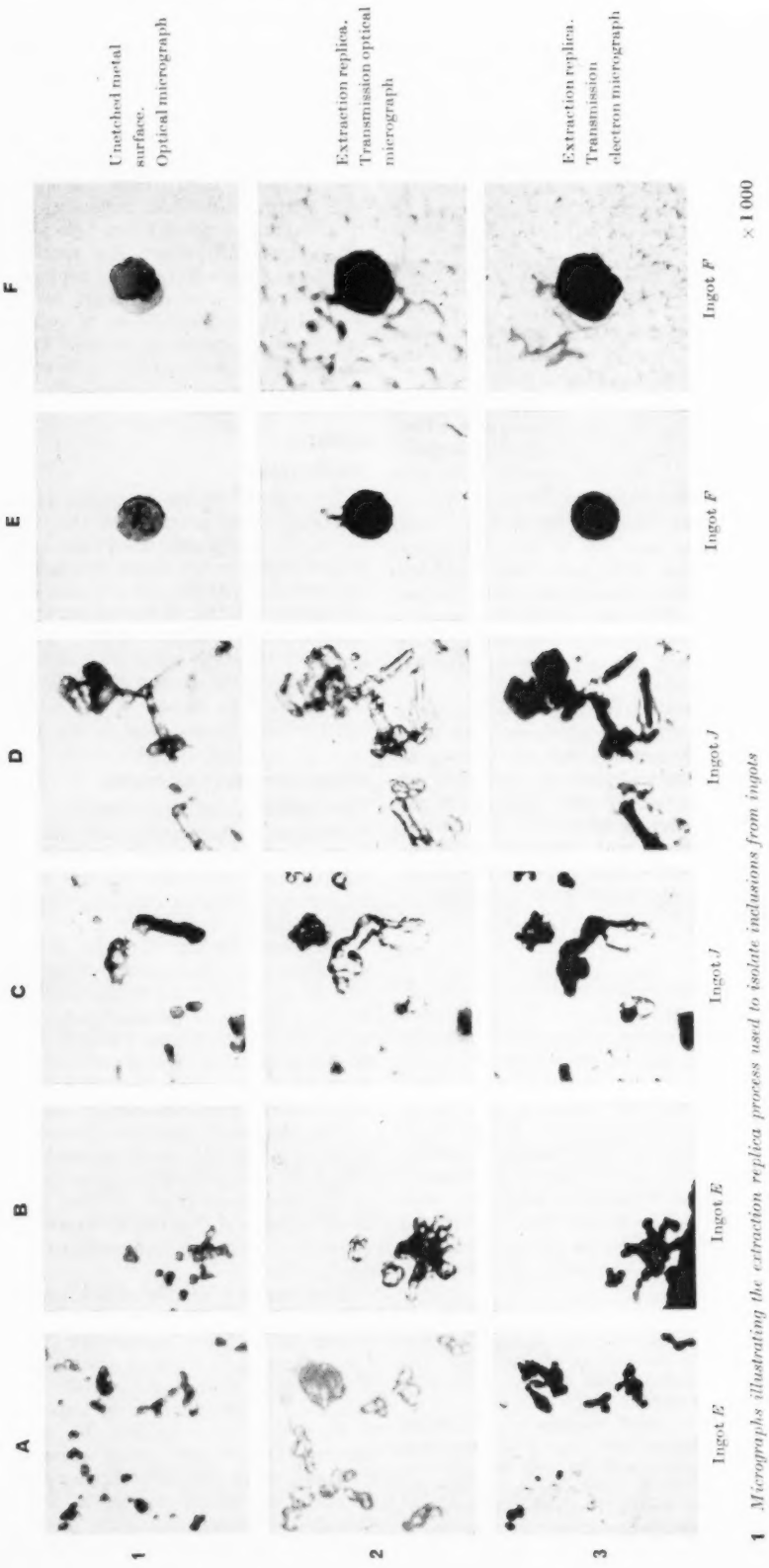
The authors were with the central research laboratories of Richard Thomas and Baldwins Ltd when this paper was written. At present Mr Booker is with the Solid State Physics Group, Westinghouse Research Laboratories, Pittsburgh, Pa., USA. Dr Norbury is at the Research Laboratories, Gillette Industries, Nr Reading, Berks, and Mr Westrope is with the Broken Hill Company, Australia.



1 *Micrographs illustrating the extraction replica process used to isolate inclusions from ingots*

TABLE I Oxygen and aluminium contents of ingots examined

Ingot	Oxygen introduced, wt-%	Aluminium introduced, wt-%	Ratio Al/O
E	0·02	0·5	25
K	0·10	1·0	10
J	0·10	0·15	1·5
F	0·02	0·01	0·50
N	0·08	0·025	0·31

The Al/O ratio for Al_2O_3 is 1·12

of the inclusion being retained in the replica, a number of particles located at the edges of the inclusion were retained and the bulk of the inclusion lost. These particles tended to be flattened and arranged symmetrically around the periphery of the inclusion (Fig.3*f*).

Normal and polarized light transmission studies on the inclusions in extraction replicas provided information which enabled the table given by Lismer and Pickering[2] concerning reflection optical microscope studies to be extended. This information is presented in Table II.

Electron diffraction

Inclusions isolated in extraction replicas from ingots *E* and *F* were examined by transmission electron diffraction. The patterns obtained were generally weak but could often be improved by using 100 kV electron accelerating voltage in preference to 50 kV or 75 kV. Most of the inclusions from ingot *E* gave patterns characteristic of α-alumina. Of the inclusions of ingot *F* that were examined about half did not give detectable electron diffraction effects, while from the remainder the magnetite pattern occurred most frequently. None of the patterns from inclusions of ingot *F* corresponded to wüstite.

X-ray diffraction

The X-ray diffraction patterns from the extraction replicas from ingots *E*, *J*, and *F* were of good quality and enabled the constituents present to be readily identified. The results of the analyses are given in Table III together with similar results for ingots *K* and *N*, the ingots being arranged in decreasing order of the ratio Al/O calculated from the total aluminium and oxygen additions. The analyses are in reasonable agreement with those found by Sloman and Evans[1] from the X-ray diffraction examination of bulk extraction residues, with the exception of ingot *J*. Since the portion of this ingot available for examination was small and contained a dense cloud of α-alumina particles along one edge, the difference is in all probability due to this pronounced segregation. The inclusions extracted from ingots *F* and *N* gave diffraction patterns in which the wüstite lines were in general diffuse compared with the lines from the other constituents.

To establish whether any of the magnetite identified could have been due to oxidation arising from the nital etch, extraction replicas were taken from ingot *F* after etching for 5 min with a considerably milder etchant, 10% iodine–alcohol solution, and again examined by X-ray diffraction. The same result was obtained indicating that magnetite was a real and appreciable constituent of the inclusions. To ascertain whether magnetite would be present in inclusions of this type if aluminium was not present, a vacuum-cast pure iron ingot to which oxygen only had been added was investigated. Metallographic examination showed the inclusions to consist entirely of wüstite, while X-ray diffraction examination of extraction replicas revealed the presence of a large amount of wüstite with only the slightest, if any, trace of magnetite.

Ingot F, examination of individual constituents

During the metallurgical etching tests on ingot *F* it was observed that immersion for 10 min in 10% hydrochloric acid completely dissolved the wüstite phase of the inclusions. After this etch the fine particles within the inclusions were absent, but many of the large idiomorphic crystals remained attached to the ferrite matrix. To obtain more information concerning the constitution of these inclusions, electron microscope, electron diffraction, and X-ray diffraction studies were made of extraction replicas taken from ingot *F* at various stages in the dissolution of the wüstite in the inclusions.

For the electron microscope study the inclusions were etched for a particular time up to 3 min with 10% hydrochloric acid–alcohol, and then isolated in extraction replicas. Examination of the replicas showed that attack of the inclusions was generally significant after ¼ min, appreciable after ¾ min, and complete after 1½ min. In most instances the initial attack was characterized by a fairly uniform decrease in the diameter of the inclusion and by the uncovering of either separate particles (Figs.4*a* and *b*) or semi-continuous layers (Fig.4*b*). The separate particles often contained a central hole and sometimes appeared too large to have come from the portion of the inclusion dissolved. However, examination revealed that many of them were flattened (Fig.4*c*), and, on being released by the hydrochloric acid, had apparently fallen over sideways before being removed in the extraction replica.

The next stage in the attack was characterized by a further reduction in the diameter of the inclusions until either large idiomorphic crystals (Fig.4*d*) or a number of smaller particles (Fig.4*e*) were revealed within the interior of the inclusions. Finally, the

TABLE II Transmission optical microscope studies on inclusions in extraction replicas

Type of inclusion	Common occurrence	Opacity	Colour with normal light	Appearance with polarized light
α-alumina, Al_2O_3	Irregular small particles frequently in groups	Translucent	Mostly colourless	Bright. Any birefringence effects too weak to be observed
Hercynite, $FeO.Al_2O_3$	Dispersed elongated particles	Translucent	Colourless to medium grey	Internal reflections but no birefringence
Wüstite, FeO-rich solid solution	Globular particles containing spinel phases	Opaque	...	...

a ×2000 *b* ×2000 *c* ×4000

2 *Electron micrographs of characteristic types of α-alumina inclusion isolated from ingot E in extraction replicas,* (a) *stringers or dumbbells,* (b) *irregular, and* (c) *angular particles*

replica structures showing the outlines of the original inclusions were observed either to contain only large idiomorphic crystals (Fig.4*f*) or were completely devoid of material.

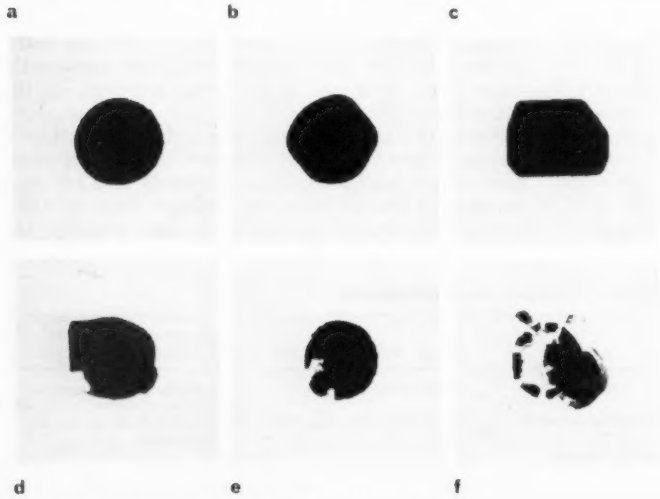
Examination of the replicas at higher magnification with the electron microscope revealed further details concerning the various constituents. Protuberances aligned in a regular manner were often observed on the surfaces of the semi-continuous layers, and separate particles closely adjacent were similarly oriented (Fig.5*a*). Of the inclusions containing small particles within the interior, on rare occasions the particles were found to be connected (Fig.5*b*) in the form of dendrites, but more frequently were separate (Fig.5*c*).

Selected-area electron diffraction studies were performed on the extraction replicas used for the electron microscope examination, the portion of the specimen contributing to the pattern being limited to a circular area of approximately 1·5 μ dia. so that different portions of individual inclusions could be separately analysed. Although the electron diffraction patterns of magnetite and hercynite are somewhat similar, a careful experimental technique combined with an accurate diffraction calibration enabled each of these phases, when it occurred, to be unambiguously identified from its pattern. The consistency of the results obtained indicates the reliability of the method of identification.

All the electron diffraction patterns thus obtained from the particles in the outer portions of the inclusions corresponded to magnetite. In particular the patterns from the outer particles in inclusions which contained a large idiomorphic crystal within the interior had sharp spots and were invariably characteristic of a single crystallographic orientation. Furthermore, the crystallographic orientation of each of these particles in an individual inclusion was the same irrespective of the position of the particle around the periphery. Less conclusive results were obtained concerning the crystallographic orientations of the outer particles present in those inclusions not containing a large idiomorphic crystal.

All the electron diffraction patterns from particles within the interior of the inclusions corresponded to hercynite. The patterns from the dendritic particles consisted of sharp spots and were characteristic of a single crystallographic orientation, while those from the separate particles comprised diffuse spots and indicated a number of poorly formed crystals only partially orientated with respect to one another. The patterns from the large idiomorphic crystals were weak and characteristic of single crystals. Although numerous partially disintegrated inclusions were examined, very few patterns corresponding to wüstite were obtained.

For the X-ray diffraction examination the specimen was given an extraction replica etch of 5 min in 10% iodine–alcohol, then etched for a selected time up to 15 min with 10% hydrochloric acid–alcohol and an extraction replica taken. In this manner the inclusions were first exposed by the extraction replica etch and then allowed to disintegrate under the action of the hydrochloric acid. The constituents so released were carried away with the hydrochloric acid and the remaining portions of the inclusions subsequently removed in the extraction replica. The X-ray diffraction analyses of these replicas when compared with the normal extraction replica analysis for this ingot



a ×4000 *b* ×4000 *c* ×4000 *d* ×2000
e ×4000 *f* ×2000

3 *Electron micrographs of characteristic types of inclusion isolated from ingot F in extraction replicas*

TABLE III X-ray diffraction determination of relative amounts of phases in inclusions isolated from ingots in extraction replicas

Constituent	Ingot *E*	Ingot *K*	Ingot *J**	Ingot *F*	Ingot *N*
α-Al_2O_3	Large	Medium	Large	...	...
$FeO.Al_2O_3$	...	Medium	...	Medium	Small
FeO	...	...	...	Medium	Medium
Fe_3O_4	...	...	...	Large	Large
Unidentified	Trace	...	Trace	Trace	Trace
Al/O	25	10	1·5	0·5	0·31

* The portion of ingot *J* available for this examination was not representative of ingot *J* as a whole.

showed that during the initial attack there was a large reduction in the amount of magnetite, a small reduction in the wüstite, and little change in the hercynite. As attack proceeded, the magnetite and wüstite continued to diminish until only hercynite remained, albeit in reduced amount. These results are in good agreement with the constitution of the inclusions deduced from the electron microscope and electron diffraction studies.

Ingot F, hydrogen reduction treatment

To differentiate further between the hercynite and iron oxide phases in the inclusions of ingot *F*, a portion of the ingot was carefully polished and optical micrographs of particular inclusions compared before and after heating the specimen for $\frac{1}{2}$ h at 800°C in dry hydrogen. The large idiomorphic crystals were completely unattacked by the treatment, characteristic of hercynite, while the surrounding material was severely attacked, characteristic of the iron oxides. The original light grey zones near the edges of the inclusions now appeared slightly darker than the normal wüstite areas. No definite conclusions could be made concerning the fine particles within the globules.

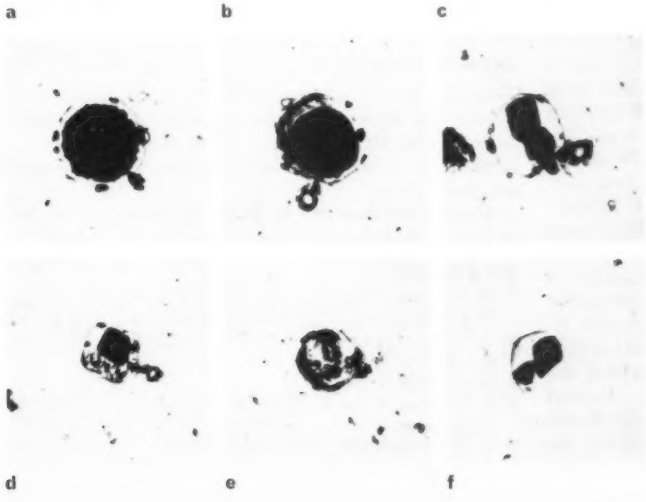
DISCUSSION

The comprehensive examination now performed has demonstrated that electron microscope, electron diffraction, and X-ray diffraction studies, at present being extensively used for precipitation processes occurring in steels, can also be applied with considerable advantage to the investigation of non-metallic inclusions. The investigation shows, furthermore, how these methods can be used to examine and identify separate constituents within individual inclusions. This new technique opens up a very wide field of application which should prove of great value in studying many metallurgical phenomena.

The examination of the inclusions in ingots *E* and *J* has confirmed the general findings of previous workers[1, 2] and provided more detailed information concerning the morphology of the inclusions. The examination of the complex inclusions of ingot *F* showed that these inclusions consisted of a wüstite matrix containing hercynite either in the form of large idiomorphic crystals, dendritic particles, or separate particles. Magnetite was also present in the wüstite at or near to the surface of the inclusions in the form of separate particles and/or semi-continuous layers.

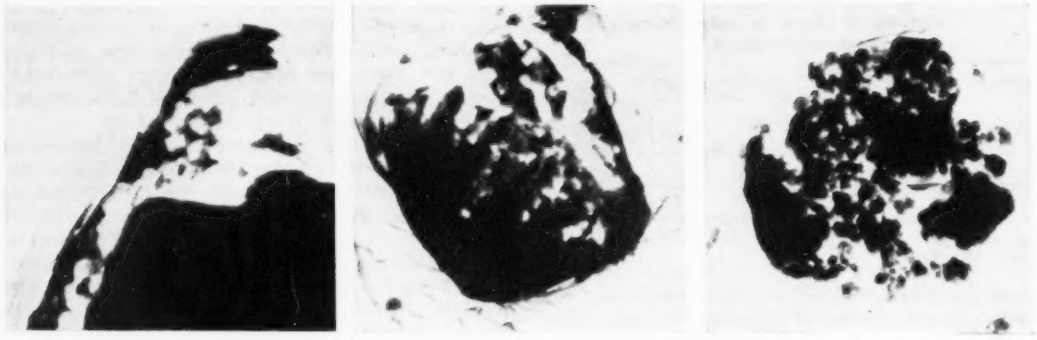
These results indicate that the light grey edge zones discernible in optical micrographs of many of the inclusions of the oxygen-rich ingots, and attributed by Sloman and Evans[1] to either a complex containing silica or to a 'disproportionation' of the wüstite, are the magnetite phase. Furthermore, the dark grey to almost black dispersed particles within these inclusions suggested by Lismer and Pickering[2] to be magnetite are now shown to be hercynite.

The mode of formation of the hercynite particles in the inclusions of the oxygen-rich ingots has been discussed in detail by Sloman and Evans.[1] Two mechanisms were thought to occur, these being (*a*) a reaction between initially precipitated alumina particles and surrounding liquid wüstite, and (*b*) a direct precipitation of hercynite. In the present investigation three different types of hercynite particles were detected within the interior of the inclusions. A possible explanation is that the separate hercynite particles, which are poorly formed crystallographically and within individual inclusions are not precisely oriented, are formed by mechanism (*a*), while the large idiomorphic hercynite crystals and the dendritic hercynite particles which are both well formed crystallographically and have precise crystallographic orientations are formed by mechanism (*b*). If this interpretation is correct, then the observations relating to the separate hercynite particles suggest that the rate of dissolution of alumina by liquid wüstite is extremely slow.



a $\frac{1}{2}$ min, ×2000 *b* $\frac{3}{4}$ min, ×2000
c $\frac{3}{4}$ min, ×2000 *d* $\frac{1}{4}$ min, ×2000
e $\frac{3}{4}$ min, ×2000 *f* $1\frac{1}{2}$ min, ×2000

4 *Electron micrographs showing the effect of immersing inclusions of ingot F for various times in 10% hydrochloric acid–alcohol solution. Extraction replicas*



a b c

a ¾ min, ×20000 *b* ¾ min, ×10000 *c* ¾ min, ×15000

5 *Electron micrographs showing details of inclusions isolated as in Fig.4,* (a) *outer magnetite particles,* (b) *inner dendritic hercynite particles, and* (c) *inner separate hercynite particles*

The presence of magnetite in the inclusions of the oxygen-rich ingots presumably arises from a breakdown of the wüstite which is unstable at temperatures below 560°C.[5] Wüstite has a range of composition, rather than a single precise composition corresponding to the formula FeO, and can break down to form magnetite in either of the following ways[1,6,7]:

$$FeO_x \rightarrow Fe + Fe_3O_4 \quad \ldots\ldots(1)$$

$$FeO_x \rightarrow FeO_{x-\Delta x} + Fe_3O_4 \quad \ldots\ldots(2)$$

where x is approximately 1. Breakdown as in equation (1) yields metallic iron and magnetite, while breakdown as in equation (2) gives wüstite of reduced oxygen content and magnetite. Any change in the amount of oxygen in the wüstite alters the size of its crystallographic unit cell by a very small amount and slightly displaces the positions of its diffraction lines. The doubling of the wüstite X-ray diffraction lines reported by Sloman and Evans,[1] and the diffuse nature of the wüstite lines compared with the lines from other constituents observed in the present investigation, are undoubtedly evidence of a breakdown of this type.

The inclusions with 'missing' portions (Fig.3*e*) are perhaps examples of a breakdown as in equation (1). Inclusions of this type suitably oriented with respect to the surface in polished sections could be the origin of the metallic particles sometimes observed in the inclusions of the oxygen-rich ingots during metallographic examinations. The central holes in the magnetite particles located at or near to the surface of the inclusions are also direct evidence of a breakdown although it has not been definitely established whether the holes originally contained wüstite or iron. The former would have been dissolved by the hydrochloric acid etch and the latter by the extraction replica etch.

Contrary to the findings of Sloman and Evans,[1] magnetite was not found in the inclusions of the ingot containing only oxygen as an addition. The result was consistently obtained during the present investigation and shows that the breakdown of wüstite is enhanced when aluminium is present.

Some of the results of the present investigation provide information regarding the manner in which the wüstite solidifies around the previously formed hercynite particles. Thus, because the magnetite forms from the solid wüstite by a diffusion process, the observation that magnetite particles within individual inclusions, regardless of their location around the periphery, possessed a single crystallographic orientation, indicates that the wüstite in these inclusions also possessed a single crystallographic orientation. Furthermore, the inclusions with magnetite particles thus oriented invariably contained within the interior a large idiomorphic hercynite crystal, strongly suggesting that the wüstite in these instances used the existing hercynite crystal as a seed for growth. If this occurred it is probable that the impurities, notably aluminium, would be pushed outwards by the advancing liquid/solid interface and would ultimately lie at or near the surface of the inclusions. It was shown earlier that the presence of aluminium enhanced the breakdown of wüstite to form magnetite. Accordingly, the above mechanism would account not only for the wüstite solidifying as a single crystal but for the magnetite in the inclusions being located at or near the surface of the inclusions.

Several of the present findings, namely, that inclusions or constituents of inclusions are often single crystals and that Widmanstätten relationships sometimes exist between separate phases within individual inclusions, probably apply to many other types of inclusion. Furthermore, because elements other than aluminium are doubtless capable of enhancing the breakdown of wüstite, magnetite formed in this manner is probably present in inclusions in a variety of steels.

ACKNOWLEDGMENTS

The authors are indebted to Mr H. A. Sloman for providing the ingots, and wish to thank their colleagues, in particular Mr V. Thomas, for useful discussions, and Mrs J. Green for valuable assistance with the experimental work.

Thanks are also due to Mr R. A. Hacking, Director of Research, for permission to publish this paper.

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The toughness of tempered martensite

D. Hardwick, B.Met., Ph.D., and K. R. Pirt, L.I.M.

SYNOPSIS

Tensile strength/transition temperature relationships have been determined for three low-alloy steels, En.21, En.25, and En.40B, in the tempered martensitic condition and at a constant prior austenite grain size. The results have been rationalized in terms of the tempering characteristics of martensite. 1895

INTRODUCTION

THE TOUGHNESS of a metal may be loosely defined as its resistance to brittle fracture. It is now generally accepted that this property can be qualitatively assessed by the temperature of the ductile-brittle transition as determined by notched-bar impact tests.

Toughness is of particular importance in large highly stressed forgings. Some recent failures of turbo-alternator components in the USA[1,2] have concentrated attention of both metallurgists and engineers on this property. Some of the factors affecting the transition temperature of En.40B (3%Cr–Mo) steel, a standard alternator rotor composition, have been examined in some detail by Cina and Jubb.[3] They showed the extent to which transition temperature could be affected by prior austenite grain size, tensile strength, the degree of temper embrittlement, and the nature of the transformation product. This latter effect is of particular importance and the lowering of transition temperature resulting from an initial transformation to martensite, rather than to bainite or pearlite, is considerable.

As part of a general programme of development of improved alternator steel compositions, the work of Cina and Jubb on En.40B was extended and two further steels, En.21 and En.25, studied. This investigation was partly concerned with the effect of tensile strength on transition temperatures of tempered martensite structures and some of the results obtained are presented below.

EXPERIMENTAL METHODS

Materials

Hot-rolled bar material $\frac{3}{4}$ in. dia. was used for all experiments. The compositions of the steels investigated are given in Table I.

Heat treatment

Except where otherwise stated all steels were austenitized for $\frac{1}{2}$ h at 900°C before transformation to martensite. This treatment resulted in prior austenite grain sizes of 7–8 ASTM in En.40B and En.25 steels and 9–10 ASTM in En.21. The effect of tensile level at a coarse austenite grain size was investigated in En.40B and a grain size of 1 ASTM was obtained by austenitizing for $\frac{1}{2}$ h at 1250°C. After this treatment specimens were transferred to a furnace at 900°C and held at this temperature for $\frac{1}{2}$ h before transformation. This latter treatment was introduced to minimize any effects on transformation behaviour associated with austenitizing temperature.

Brine- and water-quenched specimens of En.21 and En.25 had similar hardnesses, as did oil- and water-quenched specimens of En.40B. The former steels were therefore mostly water-quenched and the latter oil-quenched to reduce the incidence of quench cracking. X-ray examination of quenched specimens showed no evidence of retained austenite in En.21 or En.25 and only a trace in En.40B.

The varying tensile levels in all the steels were obtained when experimentally convenient by tempering for different times at 600–650°C, the Ac_1 temperatures of En.40B, En.21, and En.25 having been determined dilatometrically as 775°, 675°, and 695°C respectively. Low tensile levels in En.40B were obtained by tempering at 740°C, and very high tensile strengths in all steels by tempering for long times at 300–350°C or very short times at higher temperatures. Because of the known susceptibility of all three steels to temper embrittlement, tempering within the embrittling region of 450–550°C was avoided. The short-time tempering treatments were accomplished by plunging the specimens into salt baths maintained at the required temperature, previous work having established the time required for the specimens to attain any particular temperature. By this means rapid heating was assured through the temper embrittling region. After tempering at any temperature, all specimens were water-quenched.

Mechanical testing

Mechanical test results were obtained from 0·357-in. dia. tensile test pieces, machined after heat treatment as $\frac{3}{4}$-in. dia. bar. Transition curves were determined using six or eight Charpy V-notch impact test pieces. In the initial experiments, transition temperature was defined as the average of:

(i) the temperature of mean energy absorption

(ii) the temperature at which the fracture showed 50% cleavage.

Since these two temperatures differed only slightly,

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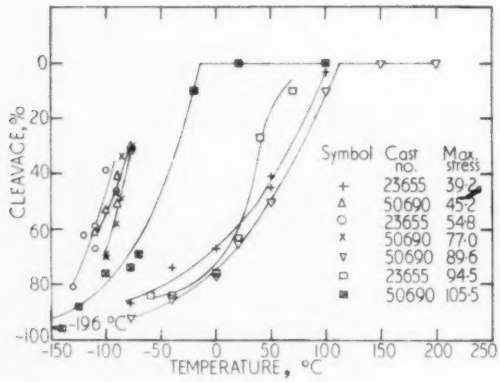
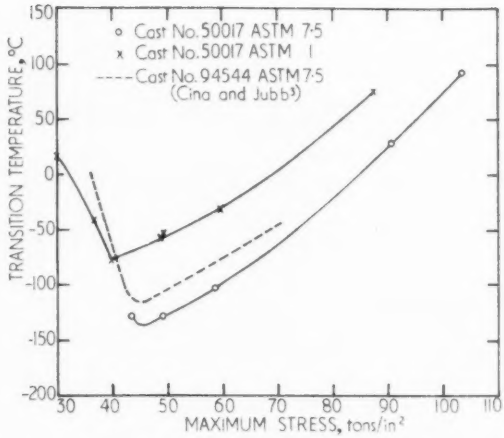


1 *Transition curves (% cleavage), En.25*


Cast No. 50017 ASTM 7·5
Cast No. 50017 ASTM 1
Cast No. 94544 ASTM 7·5 (Cina and Jubb³)
TRANSITION TEMPERATURE, °C
MAXIMUM STRESS, tons/in²

2 *Effect of tensile strength on transition temperature, En.40B. Prior austenite grain sizes ASTM 7·5 and 1*

(ii) was used as standard in the majority of the tests. At high tensile levels the determination of the percentage cleavage in a fracture was sometimes difficult and reliance was placed on the energy criterion mentioned above. A typical series of transition curves is shown in Fig.1.

EXPERIMENTAL RESULTS

En.40B (3%Cr–Mo) cast no. 50017

The effect of tensile level on transition temperature–prior austenite grain sizes 7·5 and 1 ASTM

The effect of tensile strength on transition temperature at a fine and a coarse prior austenite grain size is shown in Fig.2. The mechanical properties and heat treatments are listed in Tables II and III. Insufficient material was available to investigate the very low tensile levels at the fine prior austenite grain size but the previous results of Cina and Jubb[3] from a similar cast indicate that an inversion occurs in the tensile strength/transition temperature curve at ≃45 tons/in²; the present results suggest a similar effect. It is unlikely that the differences in transition temperature between cast nos.94544 and 50017 are due to normal compositional variations. Trace element contents may, however, differ and as Steven and Balajiva have shown,[4] this can lead to changes in transition temperature.

The mechanical properties are plotted against tensile strength in Fig.3. At very low tensile levels all the steels in this investigation showed a discontinuous yield point; at other strength levels no such yield was apparent and yielding was assessed as the 0·5% proof stress.

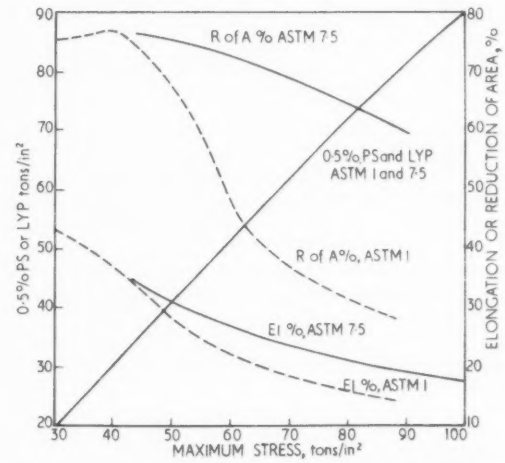
Metallographic examination of polished fractured Charpy specimens revealed little evidence of marked structural change with tensile strength until values approaching the inversion strength were reached. At and below this tensile level marked ferrite grain growth could be detected with carbide spheroidization and a change in ferrite grain shape from acicular to polygonal. Typical photomicrographs are shown in Fig.4*a–d*.

En.21 (3%Ni) cast nos. 53773 and 65937

The effect of tensile strength on transition temperature–prior austenite grain size ASTM 9·5

The tensile strength/transition temperature relationship at a constant prior austenite grain size is given in Fig.5, the details of the heat treatment in Table IV and the mechanical properties in Fig.6. The results from the two casts examined are in good agreement.

The tensile strength/transition temperature curve shows a rapid rise in transition temperature with increasing tensile strength above 65 tons/in² and with decreasing tensile strength below 40 tons/in². At tensile strengths within these limits little change in transition temperature occurs and very little difference in ferrite grain size can be seen (*see* Figs.7*a* and *b*). That the low tensile inversion is associated with a marked increase in ferrite grain size together with carbide spheroidization is shown in Figs.7*c* and *d*. The reduction in area values show some evidence of a slight ductility 'trough' at the high tensile levels at which high transition temperatures are apparent. At low strength levels the reduction in area values show little change with decreasing tensile strength; a similar effect was observed in En.40B ASTM 1.

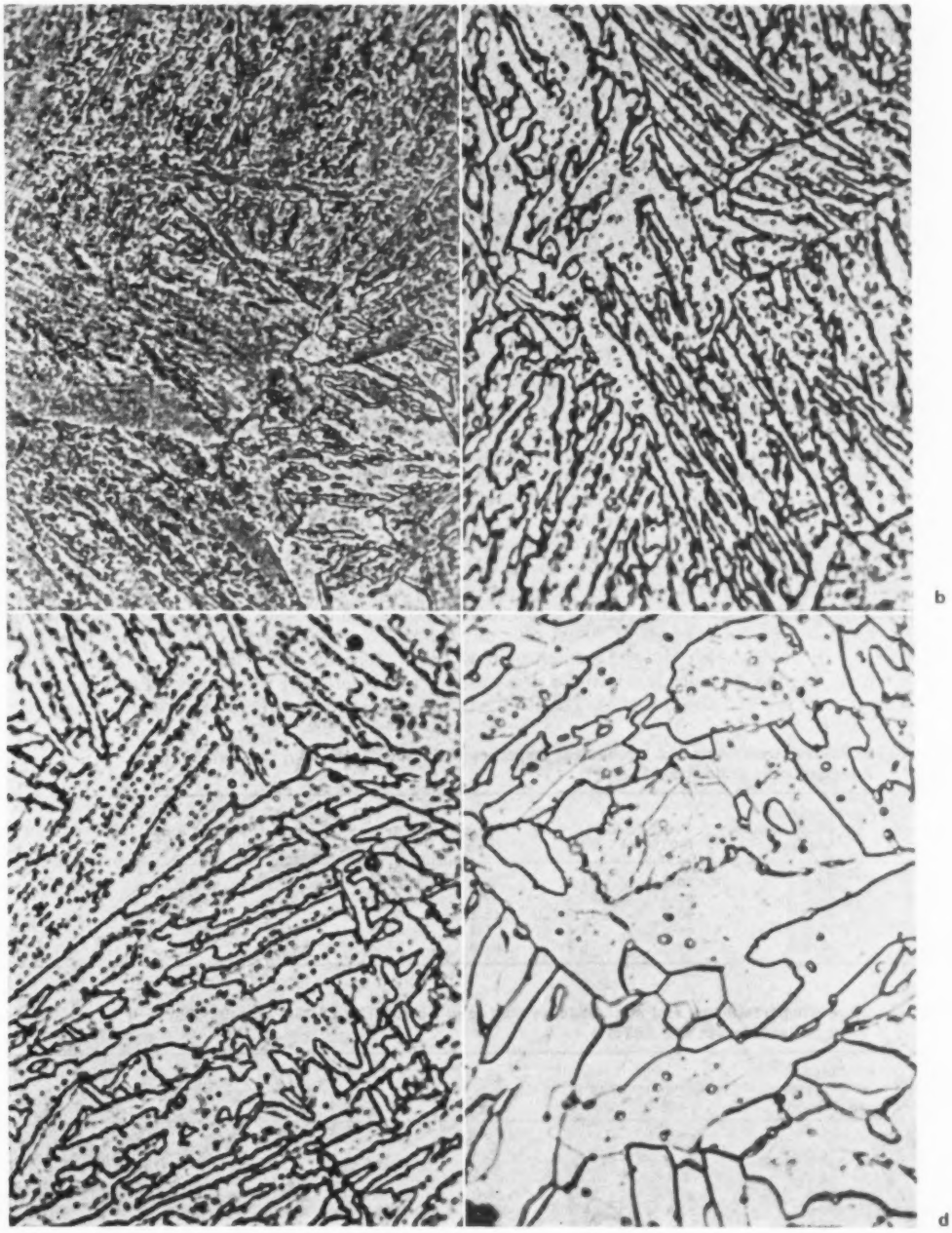

R of A % ASTM 7·5
0·5% PS and LYP ASTM 1 and 7·5
R of A%, ASTM 1
El %, ASTM 7·5
El %, ASTM 1
0·5% PS or LYP tons/in²
ELONGATION OR REDUCTION OF AREA, %
MAXIMUM STRESS, tons/in²

3 *Mechanical property/tensile strength curves, En.40B. Prior austenite grain sizes ASTM 7·5 and 1*

TABLE I Composition of steels investigated, wt-%

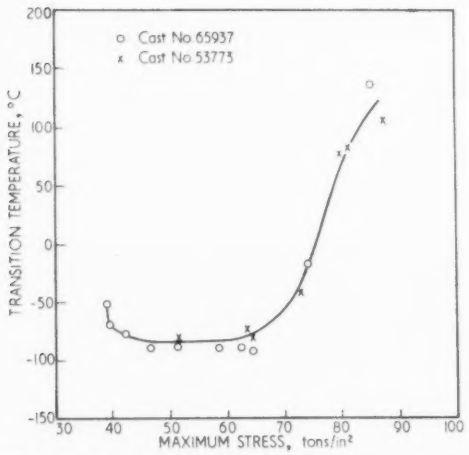
Cast no.	Quality	C	Si	Mn	S	P	Cr	Ni	Mo
94544* (BEA)	En 40B	0·26	0·24	0·50	0·003	0·012	3·12	0·26	0·53
50017 (BEA)	En 40B	0·27	0·22	0·48	0·011	0·014	3·08	0·15	0·53
53773 (BEA)	En 21	0·33	0·25	0·58	0·007	0·011	0·20	3·12	...
65937 (BEA)	En 21	0·32	0·27	0·61	0·019	0·014	0·08	3·05	...
23655 (S)	En 25	0·31	0·20	0·61	0·032	0·021	0·82	2·40	0·65
50690 (BEA)	En 25	0·27	0·21	0·65	0·006	0·010	0·70	2·62	0·60

* From Cina and Jubb[3] (BEA) Basic electric arc (S) Acid Siemens

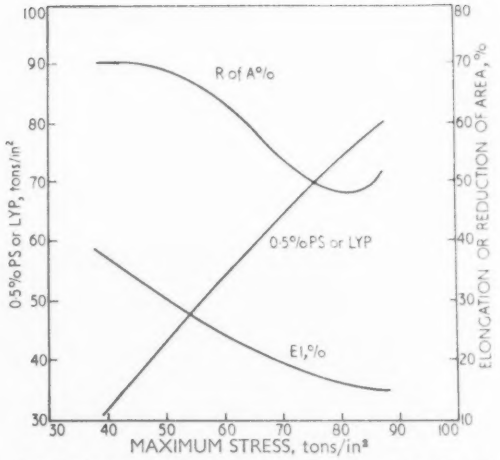


Maximum stress, tons/in²
a 49·0 *b* 39·6 *c* 36·7 *d* 30·0

4 *En.40B, microstructures of Charpy specimens, ASTM 1. Etched 2% nital* ×2000



5 *Effect of tensile strength on transition temperature, En.21. Prior austenite grain size ASTM 9·5*



6 *Mechanical property/tensile strength curves, En.21. Prior austenite grain size ASTM 9·5*

En.25 (2½%Ni–Cr–Mo) cast nos. 23655 and 50690

The effect of tensile strength on transition temperature–prior austenite grain size ASTM 7·5

The transition temperatures and the mechanical properties as functions of tensile strength at a constant prior austenite grain size of ASTM 7·5 are given in Figs.8 and 9 respectively. The heat treatments are listed in Table V. The curve in Fig.8 shows similar features to the transition temperature/tensile strength curve of En.21. The low stress inversion occurs at 45 tons/in² and the rapid rise in transition temperature with tensile strength at high strength levels occurs at ≃80 tons/in². A specimen tested in the untempered condition showed a lower transition temperature than specimens tempered to stress levels of 90–95 tons/in². The reduction in area values showed evidence of a ductility trough at high strength levels and a decrease in ductility at very low tensile strengths. The strength level at which this occurs is that of the low strength inversion. The photomicrographs in Figs.10*a–d* show the features previously observed in the other two steels. For comparison the tensile strength/transition temperature curves of all the steels investigated are shown together in Fig.11.

DISCUSSION

The transition temperature/tensile strength curves of En.21 and En.25 within the limits of tensile level investigated show three distinct parts. In part *A* at low tensile levels, an increase in tensile strength leads to a marked decrease in transition temperature. At high tensile levels is part *C* in which an increase in tensile strength produces a marked increase in transition temperature. Part *B* comprises intermediate stress levels over which little or no change in transition temperature occurs. It is probable that at very high

TABLE II Tempering treatments and mechanical properties of En.40B (3%Cr–Mo) cast no. 50017. Prior austenite grain size ASTM 7·5

Tempering treatment	Limit of proportionality, tons/in²	Proof stress, tons/in² 0·05%	0·1%	0·2%	0·5%	Max. stress, tons/in²	Elong., %	R. of A., %	Trans. temp., °C
96 h/650°C	20·0	30·2	31·6	32·9	34·0	43·5	35	76½	−127
16 h/650°C	23·0	36·5	38·4	39·9	40·0	49·0	30½	75½	−127
4 h/650°C	31·0	44·3	46·5	48·1	50·0	58·7	27	73½	−102
5 min/600°C	39·0	64·6	71·3	77·2	82·7	90·2	20½	59½	+30
16 h/350°C	52·0	74·9	78·6	84·5	92·5	103·5	16	53½	+92

TABLE III Tempering treatments and mechanical properties of En.40B (3%Cr–Mo) cast no. 50017. Prior austenite grain size ASTM 1

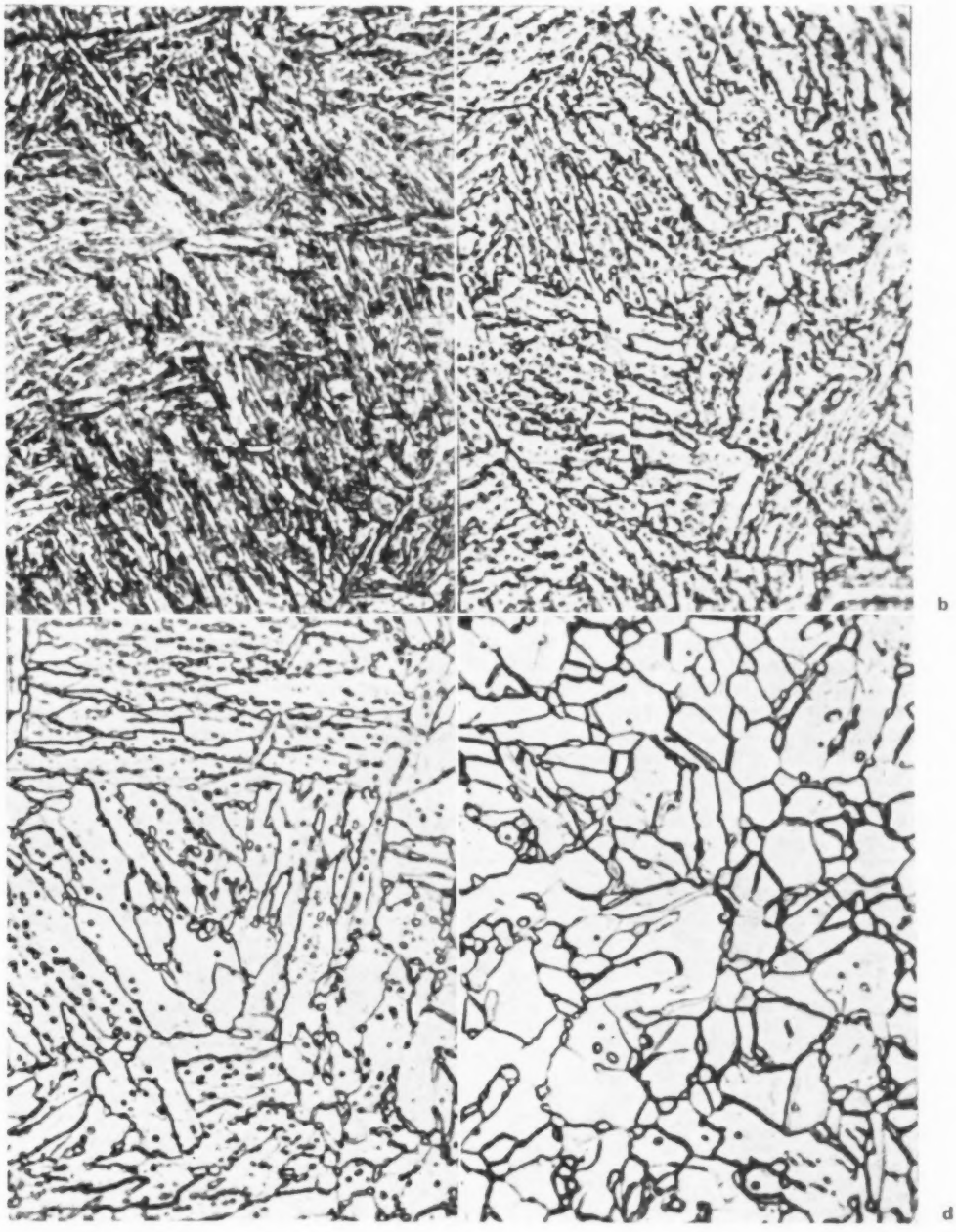
Tempering treatment	Limit of proportionality, tons/in²	Yield point or proof stress, tons/in²				Max. stress, tons/in²	Elong., %	R. of A., %	Trans. temp., °C
		UYP		LYP					
1008 h/740°C	20·0	21·0		19·6		30·0	43	75½	+16
		0·05%	0·1%	0·2%	0·5%				
168 h/740°C	23·0	26·0	26·0	26·0	26·0	36·7	40	75	−39
24 h/740°C	22·0	27·5	28·0	28·6	29·0	39·6	37½	77	−77
58 h/650°C	27·0	37·0	38·3	39·3	40·8	48·6	29	69	−57
16 h/650°C	29·0	37·9	38·9	40·0	41·0	49·0	29½	69	−53
2 h/650°C	36·0	46·3	48·2	50·0	52·5	59·8	22	48½	−31
5 min/600°C	35·0	62·5	68·7	74·5	81·0	87·5	14½	28	+75

tensile levels a further decrease in transition temperature results as previously reported.[5] There is some evidence of this in En.25.

The curves of En.40B in both fine- and coarse-grained prior austenite conditions show evidence of part *A* but parts *B* and *C* are not easy to distinguish. It is possible that further test results within the tensile range of 60–80 tons/in^2 would reveal the presence of an inflexion in the curves indicating a separation into parts *B* and *C*. Because of shortage of material, however, such tests were not carried out.

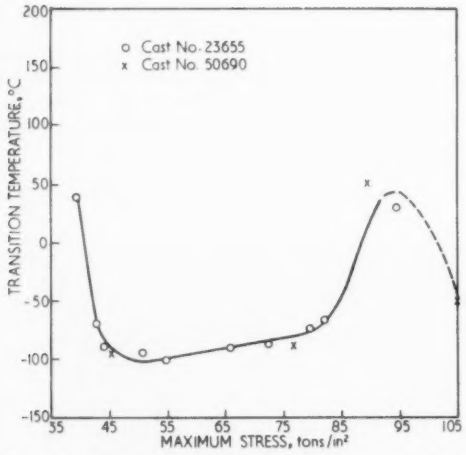
It is interesting to consider the shape of the tensile strength/transition temperature curves in relation to the generally accepted theories of the tempering of martensite bearing in mind that most of the work on tempering has been carried out not on alloy but on plain carbon martensites.

The rapid rise in transition temperature with tensile

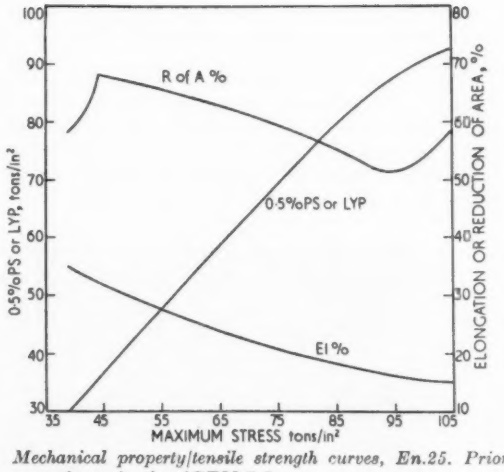


Maximum stress, tons/in^2
a 85·2 *b* 46·5 *c* 39·7 *d* 39·0

7 *En.21, microstructures of Charpy specimens. Etched 2% nital* ×2000



8 *Effect of tensile strength on transition temperature, En.25. Prior austenite grain size ASTM 7·5*



9 *Mechanical property/tensile strength curves, En.25. Prior austenite grain size ASTM 7·5*

strength in En.21 and En.25 at high tensile levels (part *C* of the curves) is most certainly a manifestation of '350°C embrittlement'. It has been suggested[6, 7] that this embrittlement is in some way related to the solution of ϵ carbide and the precipitation of cementite early in the third stage of tempering although the work of Capus and Mayer[8] on high-purity vacuum-melted Ni–Cr–Mo steel suggests that it is associated with trace impurities. Lement *et al.*[6] accept that '350°C embrittlement' is associated with cementite precipitation and suggest that since such precipitation occurs at martensite boundaries, crack nucleation and propagation is facilitated there. Thus brittle fracture is to be expected.

In general the tensile strengths giving rise to embrittlement were obtained by tempering within the temperature range 300–350°C. That this treatment had not induced temper embrittlement with consequent rise in transition temperature is suggested by the fact that specimens previously tempered at 600–650°C showed no change in transition temperature on being given an additional treatment at 300–350°C.

The rise in transition temperature with tensile level in both fine and coarse grained prior austenite samples of En.40B may be due to a similar embrittlement although in this steel the effect appears to persist to lower tensile levels. The effect of silicon in retarding the precipitation of cementite and hence delaying the onset of embrittlement is well known[9–11] and it is possible that chromium behaves in a similar though less potent manner. Clearly further work on the tempering behaviour of this steel at high tensile levels is required.

The existence of a range of tensile strength in En.21 and En.25 over which little or no increase in transition temperature occurs is of some importance commercially. This result is surprising for theoretically, other things being equal, a rise in transition temperature with increase in yield stress is to be expected.[12] In this investigation a continuous rise in proof stress occurred with tensile strength; an increase in transition temperature therefore, would also be expected from an increase in tensile strength.

Optical microscopic examination of specimens showing wide variations in tensile strength for similar

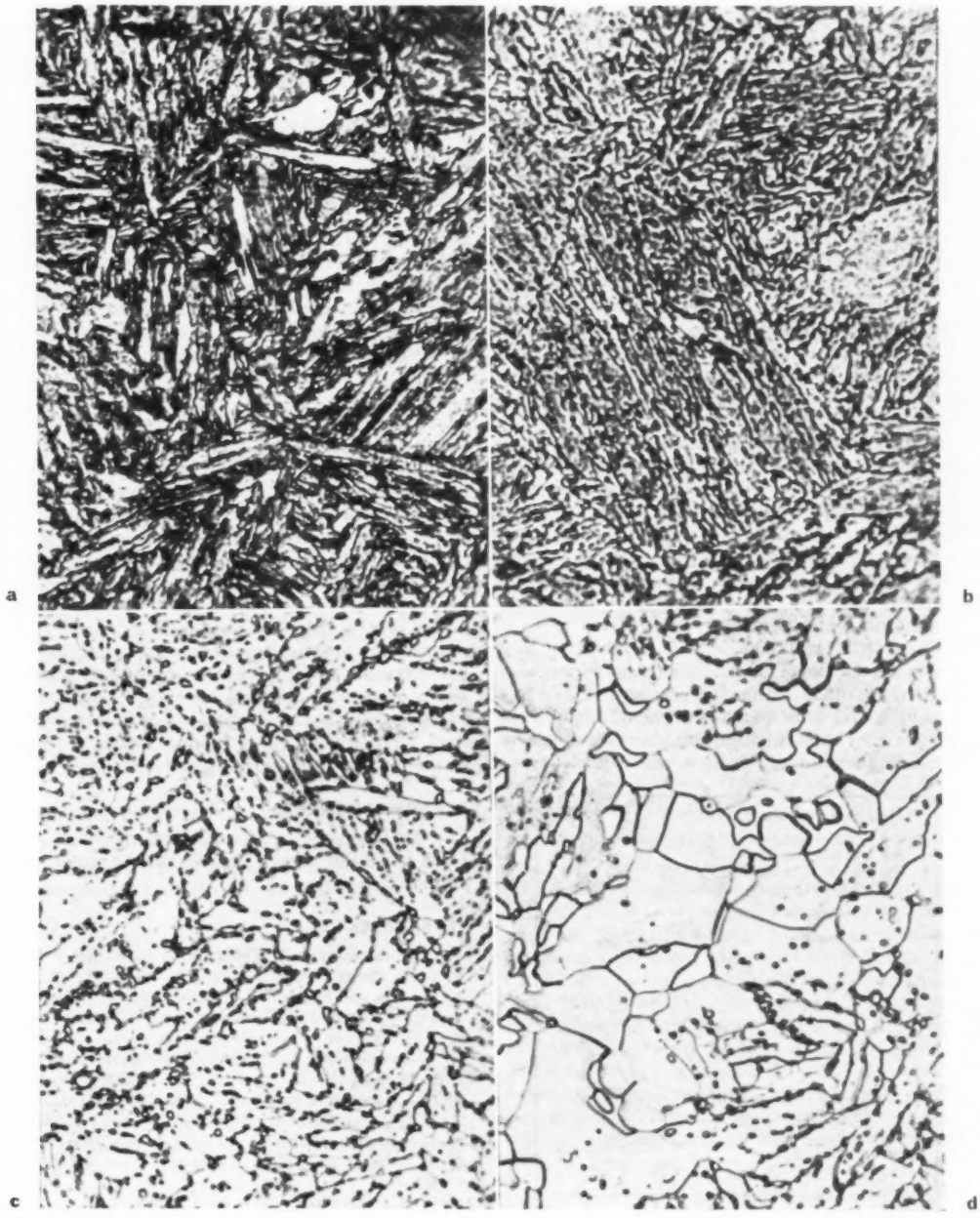
TABLE IV Tempering treatments and mechanical properties of En.21 (3%Ni) cast nos. 53773 and 65937. Prior austenite grain size ASTM 9·5

Cast no.	Tempering treatment	Limit of proportionality, tons/in²	Yield point or proof stress, tons/in²				Max. stress., tons/in²	Elong., %	R. of A., %	Trans. temp., °C
53773			UYP		LYP					
	4 h/625°C	42·5	45·4		44·0		51·6	29	67½	−78
			0·05%	0·1%	0·2%	0·5%				
	10 min/625°C	52·5	57·4	57·4	57·4	57·4	63·4	24½	62½	−74
	1 min/600°C	53·0	59·2	59·2	59·2	59·2	64·2	23	61½	−80
	168 h/350°C	67·0	71·6	72·2	72·7	73·0	79·7	15	46	+77
	64 h/350°C	69·0	72·3	72·8	73·7	75·4	81·2	16	47½	+81
	2 h/350°C	72·5	77·2	77·7	78·0	78·4	87·2	16	51½	+106
65937			UYP		LYP					
	672 h/650°C	29·5	35·2		32·4		39·0	37½	70	−52
			0·05%	0·1%	0·2 %	0·5%				
	128 h/625°C*	26·0	31·0	31·0	31·0	31·0	39·7	31	59	−70
	48 h/625°C*	24·0	33·7	34·0	34·0	34·0	42·1	28	56	−78
	8 h/625°C*	29·0	38·0	38·9	39·0	39·0	46·5	26½	50	−90
	3 h/625°C	38·0	44·0	44·0	44·0	44·0	51·2	28	67	−88
	10 min/625°C*	41·0	51·1	52·0	52·0	52·0	58·7	18½	42	−90
	5 min/600°C	44·0	53·4	54·7	55·8	56·0	62·5	22½	60	−88
	1 min/600°C	47·0	54·6	55·6	56·9	58·0	64·1	23	60	−93
	16 h/400°C	55·0	64·7	65·6	66·7	68·0	74·0	16	50½	−18
	65 h/300°C	67·0	74·1	75·0	76·2	78·0	85·2	14	49½	+135

* Tensile specimens contained cracks

values of transition temperature showed little evidence of marked structural differences. No changes in ferrite grain size could be detected and the structures remained essentially acicular in form. Resolution was insufficient to show the extent of any changes in size and distribution of carbide particles. That little change in ferrite grain size occurred with tempering temperature was reported by Lement *et al.*[13] who studied third-stage tempering reactions in plain carbon steels with the aid of the electron microscope. They attributed this to the inhibiting effect of grain boundary cementite on ferrite boundary migration. Since in their work a decrease in tensile strength occurred with the progress of tempering, this must be attributed to a decrease in the carbon content of the α lattice and the change in size and distribution of carbide particles rather than to an increase in ferrite grain size.

In part *B* of the transition temperature/tensile strength curves of En.21 and En.25, little change in



Maximum stress, tons/in^2
a 72·4 *b* 54·8 *c* 44·0 *d* 39·2

10 *En.25, microstructures of Charpy specimens. Etched 2% nital* ×2000

TABLE V Tempering treatments and mechanical properties of En.25 (2½%Ni–Cr–Mo) cast nos. 23655 and 50690. Prior austenite grain size ASTM 7·5

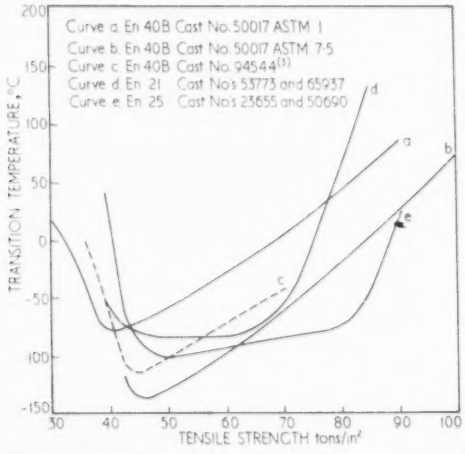
Cast no.	Tempering treatment	Limit of proportionality, tons/in²	Yield point or proof stress, tons/in²				Max. stress, tons/in²	Elong., %	R. of A., %	Trans. temp., °C
23655			UYP		LYP					
	672 h/650°C	29·3	32·3		30·3		39·2	34½	58½	+38
	336 h/650°C	34·0	37·0		34·0		42·7	33	61½	−70
	144 h/650°C	34·0	36·4		35·6		44·0	33	68	−87
	56 h/650°C	40·0	44·0		42·4		50·3	30	66	−96
			0·05%	0·1%	0·2%	0·5%				
	12 h/650°C	38·0	46·7	47·0	47·0	47·0	54·8	26½	65	−102
	3 h/650°C	46·0	57·0	58·4	59·7	60·0	66·0	23½	62½	−91
	10 min/650°C	49·0	61·5	63·5	65·0	67·6	72·4	21½	60½	−87
	10 min/600°C	58·0	68·0	69·6	71·3	73·9	79·6	21	59	−75
	5 min/575°C	61·5	70·2	71·3	73·2	76·0	82·0	20	57	−69
	64 h/300°C	70·0	75·7	76·9	78·9	82·3	94·5	15½	51	+29
50690			UYP		LYP					
	144 h/650°C	37·7	39·9		37·0		45·2	31	70	−94
			0·05%	0·1%	0·2%	0·5%				
	5 min/600°C	54·0	65·3	67·8	70·3	73·1	77·0	25	65½	−87
	64 h/350°C	68·0	75·8	77·1	79·5	84·8	89·6	17	56½	+50
	Nil	53·6	71·8	76·3	83·1	93·2	105·5	17½	59	−52

ferrite grain size with tensile strength appears to occur and the change in the latter must be due therefore to the same factors affecting the hardness in the work of Lement *et al.*[13] These factors therefore do not appear to affect transition temperature in these steels. In alloy steels changes in carbide composition can occur at the end of stage 3 tempering and it is possible therefore that the exact form of part *B* of the transition temperature/tensile strength curve is determined by the operation of this effect and hence by composition. It is interesting to note that as the chromium plus molybdenum content of the steels investigated increases, the stress dependence of transition temperature increases.

At very low tensile levels in all the steels, prolonged tempering resulted in marked ferrite grain growth and coalescence of carbides, the latter effect presumably determining the extent of the former. This marked increase in ferrite grain size, although resulting in a decrease in tensile level, nevertheless gave rise to a marked increase in transition temperature. This effect is well known and is sometimes termed 'upper nose embrittlement'. That transition temperature increases with decreasing tensile level in that part of the curve in which ferrite grain growth occurs, and is relatively insensitive to tensile strength in the stress range where changes in ferrite grain size are not thought to be significant, suggests that ferrite grain size is possibly the most important single variable in determining transition temperature.

Since in general the lower the transformation temperature of austenite the finer the ferrite grain size of the transformation product, the lower transition temperature of martensite over bainite and pearlite is explained. It has been shown previously[3] and confirmed in this investigation, that an increase in prior austenite grain size leads to an increase in transition temperature. Since fracture is influenced by ferrite grain size it might be expected that the larger the austenite grain size the larger that of the ferrite. In general this is probably true. Further electron microscopic investigation on this subject would be of interest.

From the practical point of view therefore, to attain a low transition temperature a minimum ferrite grain size is of extreme importance and if possible a composition should be chosen with tempering characteristics such that within the range of stress required; the transition temperature is insensitive to tensile strength.



11 *Tensile strength/transition temperature curves, En.40B, En.21, and En.25*

ACKNOWLEDGMENTS

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Sulphide capacities of silicate melts

PART I

K. P. Abraham, M. W. Davies, and F. D. Richardson

SYNOPSIS

Sulphide capacities, wt-%S$(p_{O2}/p_{S2})^{\frac{1}{2}}$, have been measured for the system $MnO+SiO_2$ *at 1500°C and 1650°C and for the pseudo-binary mixtures* $MnO.SiO_2+CaO.SiO_2$, $MgO.SiO_2+CaO.SiO_2$ *at similar temperatures. The results show that in* $MnO+SiO_2$ *melts, the activity coefficient of manganese sulphide at concentrations up to 2 mol-% varies by a factor of three across the range of composition of the liquids. For* $MgO.SiO_2+CaO.SiO_2$ *the sulphide capacities vary across the pseudo-binary in the way to be expected if the heat of the reaction,* $\frac{1}{2}S_2+(O'')=\frac{1}{2}O_2+(S'')$, *varies linearly with composition, while the entropy remains constant. Thus they follow the Flood–Grjotheim equation log* $K_{(X,Y)}=N_X$ *log* K_X+N_Y *log* K_Y, *where* N_X, N_Y *are the cation fractions and* K_X, K_Y *are the equilibrium constants in the presence of one cation only. For* $MnO.SiO_2+CaO.SiO_2$ *the sulphide capacities deviate by a maximum of 30% from this relationship, the deviation being associated with higher than 'ideal' activity coefficients for* MnO *in these same melts.*

1871

THE SULPHUR-HOLDING PROPERTIES of slags can best be expressed in terms of their sulphide capacities.[1] These are defined by the equation,

$$C_S=(\text{wt-\%S})\ p_{O_2}^{\frac{1}{2}}/p_{S_2}^{\frac{1}{2}},$$

and best derived from measurements of the equilibrium,

$$\tfrac{1}{2}S_2+(O'')=\tfrac{1}{2}O_2+(S'')$$

where (O″) represents the replaceable oxygen in the slag and (S″) the dissolved sulphur, which is present as sulphide under the range of conditions of most interest to the metallurgist. This equilibrium was first studied by Fincham and Richardson[1] who showed that at oxygen pressures less than about 10^{-5} atm and temperatures of 1500–1650°C, the sulphur is present almost entirely as sulphide; sulphate only becomes significant when the oxygen exceeds 10^{-3} atm.

This paper gives the results of sulphur capacity measurements that have been made with mixtures of $MnO+SiO_2$ and $MnO+SiO_2+CaO$ at 1500° and 1650°C, by a technique similar to that already described.[1] A series of measurements have also been made with mixtures running across the pseudo-binaries $CaO.SiO_2+MgO.SiO_2$ and $MgO.SiO_2+MnO.SiO_2$. The results make it possible to test the equation developed by Flood[2] for the calculation of equilibrium constants for reactions involving complex melts, from the corresponding constants for simple melts.

EXPERIMENTAL CONDITIONS

Materials

Manganese oxide, lime, magnesia, silica, and alumina were all prepared as previously described.[3]

Containers

The oxide samples were held in platinum cups made from metal foil 0·005 in. thick and holding about 0·5 g of oxide each.

Gas mixtures

Mixtures of H_2, CO_2, SO_2, and oxygen-free N_2 were used, the proportions being adjusted to give the oxygen and sulphur potentials required at the temperature of the experiments. Sulphur dioxide was taken from syphons and dried with calcium chloride. The remaining gases were taken from cylinders and dried with magnesium perchlorate.

Equilibrium apparatus and procedure

This was similar to that used by Fincham and Richardson[1] but modified as described elsewhere.[3] Manganese was absorbed from the melts by the platinum cups in amounts which varied with oxygen pressure and time, but the losses never exceeded 5 mole-%. In order to obtain sulphide capacities for $MnO+CaO+SiO_2$ melts, which had precisely the metasilicate composition, it was necessary to make measurements with a series of mixtures covering a small range of MnO concentrations at each $CaO:SiO_2$ ratio, and to analyse the slag for manganese after each experiment. The sulphide capacity at each metasilicate composition was then obtained by interpolation.

Analysis

The sulphur was determined by combustion in carbon dioxide.[4] The manganese oxide was determined colorimetrically.[3]

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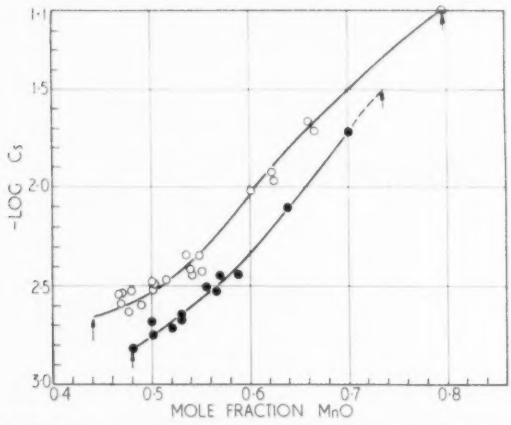
This work was carried out by the Nuffield Research Group in Extraction Metallurgy and was sponsored by the British Iron and Steel Research Association. Dr Abraham is now with the Indian Institute of Science, Bangalore, and Dr Davies is with the General Electric Co. Ltd, Erith, Kent. Professor Richardson is Professor of Extraction Metallurgy at Imperial College, London SW7.



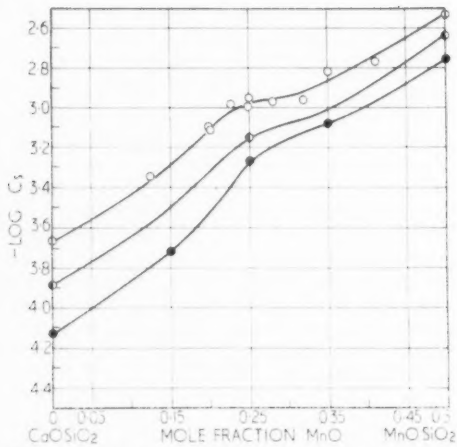
1 *Sulphide capacities (wt-%) of* $MnO+SiO_2$ *melts shown as a function of mole fraction: 1650°C (upper curve) and 1500°C (lower curve). The arrows indicate the limits of saturation with* MnO *and* SiO_2

RESULTS

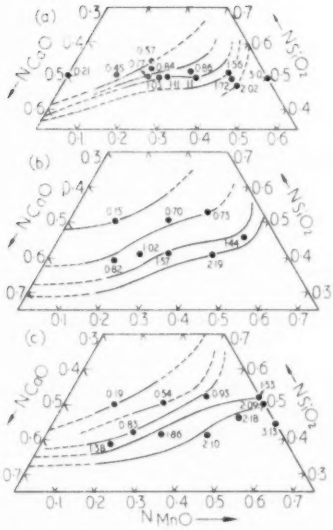
The results obtained for mixtures of $MnO+SiO_2$ at 1500° and 1650°C are shown in Fig.1. The results for the pseudo-binary $MnO.SiO_2+CaO.SiO_2$ are shown in Fig.2*a* for 1650°, 1575°, and 1500°C, while Fig.3 shows all the experimental results from which the points in Fig.2*a* have been derived. The results for the pseudo-binary $CaO.SiO_2+MgO.SiO_2$ at 1650°C are shown in Fig.4.

To derive the sulphide capacities from the measured sulphur contents of the slags and the compositions of the ingoing gases, the partial pressures of S_2 and O_2 developed in the hot zone of the furnace have to be calculated. The data used were as follows:

$CO+\frac{1}{2}O_2=CO_2$[5]	$\Delta G^\circ=-67878+21{\cdot}52T-0{\cdot}1044\times10^{-3}T^2$ log T
$H_2+\frac{1}{2}O_2=H_2O$[5]	$\Delta G^\circ=-50245+14{\cdot}73T-3521$ log T
$H_2+\frac{1}{2}S_2=H_2S$[6]	$\Delta G^\circ=-21580+11{\cdot}805T$
$\frac{1}{2}H_2+\frac{1}{2}S_2=HS$[6,7]	$\Delta G^\circ=8000+6T$
$CO+\frac{1}{2}S_2=COS$[6]	$\Delta G^\circ=-22860+18{\cdot}70T$
$\frac{1}{2}S_2+\frac{1}{2}O_2=SO$[7]	$\Delta G^\circ=-15354-1{\cdot}24T$
$\frac{1}{2}S_2=S$[7]	$\Delta G^\circ=42920-14{\cdot}41T$



2a *Sulphide capacities in wt-%, in the pseudo-binary* CaO. $SiO_2+MnO.SiO_2$ *at 1650°C (top), 1575°C (middle), and 1500°C (bottom curve)*



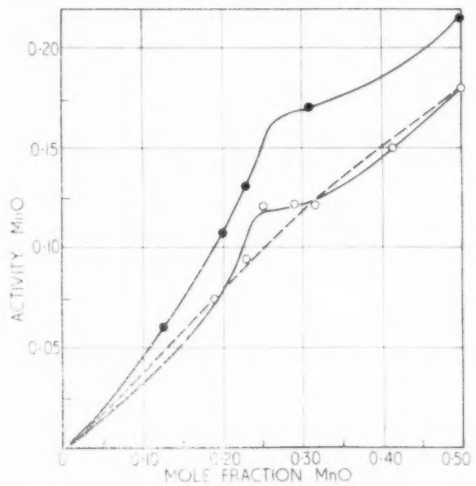
3 *Sulphide capacities in wt-%* $\times 10^3$, *in the ternary* $MnO+CaO+SiO_2$ *at* (a) *1650°C*, (b) *1575°C*, *and* (c) *1500°C*

DISCUSSION

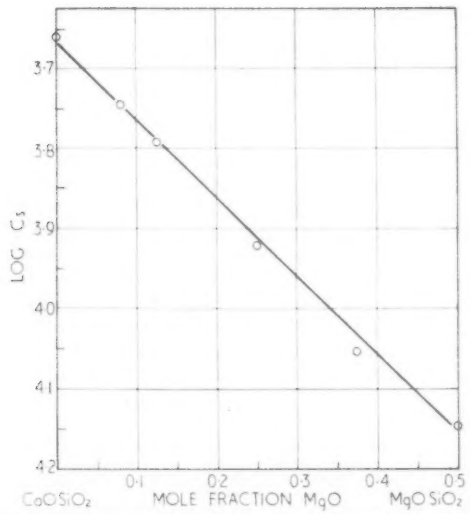
Errors

Temperature (reading and calibration of optical pyrometer)	±6°C
Gas composition (calibration and reading of flow meters)	±1%
Analysis (Mn in slag)	±1%
(S in slag)	±2%
Slag composition (apart from MnO)	negligible

In the opinion of the authors, the effect of these errors would be to cause a standard deviation of ±5% in the measured sulphur contents. This is rather less than that observed in Fig.1. The errors in the derived data particularly in the values of $p_{S2}^{\frac{1}{2}}$, $p_{O2}^{\frac{1}{2}}$, and C_S cannot be precisely assessed. Changes in the values used for



2b *The activities of* MnO *in the pseudo-binary* $CaO.SiO_2+MnO.SiO_2$ *at 1650°C (lower curve), and 1500°C (upper curve). Broken line 'ideal' curve*[3] *at 1650°C*



4 *Sulphide capacities in wt-% in the pseudo-binary* MgO.SiO_2+CaO.SiO_2 *at 1650°C*

the free energies of formation of SO and S[7] and hence HS since 1954, have changed $p_{S_2}^{\frac{1}{2}}/p_{O_2}^{\frac{1}{2}}$ by 50%, so it would be reasonable to suppose that the absolute values both of this ratio and C_S are correct to within ±30%. The relative values of C_S do not contain this error.

MnO+SiO_2 *melts*

Figure 1 shows that the sulphide capacity falls as the proportion of silica increases and the manganese oxide activity decreases. The MnO activities being known in all these mixtures,[3] it is possible to calculate the activity coefficients of MnS using the available data,[5, 6, 8] for the pure phase reaction,

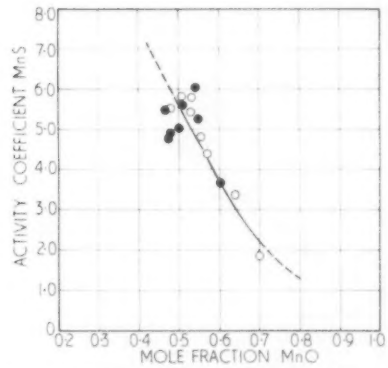
$$MnO(s)+\tfrac{1}{2}S_2=MnS(s)+\tfrac{1}{2}O_2$$

for which $\Delta G^\circ=+18165+3520 \log T-2{\cdot}975T$ cal, and Coughlin's[9] heat of fusion of MnS, 6240 cal. deg.$^{-1}$ mole^{-1} at 1530°C. Values of the molar activity coefficients of MnS (standard state liquid) at low concentrations at 1500°C and 1650°C are shown in Fig.5. The coefficient varies substantially across the range of compositions studied: thus the assumption made by Carter and Macfarlane[10] concerning the constancy of the activity coefficients of CaS in CaO+SiO_2 melts is probably in error and their derived CaO activities open to some doubt. If the activity coefficients are quoted relative to solid MnS, those at 1500°C will have to be multiplied by 1·03 and those at 1650°C by 0·89.

The relative values of C_S are accurate to about ±7% and those of a_{MnO} to ±8%. The values of γMnS are thus accurate only to within ±11% and it follows that significant values for the heats of solution of MnS in the melts cannot be derived from the variation of γMnS with temperature.

Pseudo-binary melts

Figures 2 and 4 show how the sulphide capacities vary with composition across the two metasilicate pseudo-binaries. For CaO.SiO_2+MgO.SiO_2 the logarithm of the sulphide capacity is a linear function of composition, while for CaO.SiO_2+MnO.SiO_2 this is only approximately so. From a theoretical standpoint it is



5 *Activity coefficients of* MnS *relative to liquid* MnS *in* MnO+SiO_2 *melts, open circles at 1500°C, filled circles 1650°C*

best to express the sulphide capacities in mole fractions of sulphide,* so that the effects of the differing atomic weights of manganese, calcium, and magnesium are eliminated.

The molar sulphide capacity in a metasilicate may be regarded as the equilibrium constant for the reaction

$$\tfrac{1}{2}S_2+2(\vdots Si-O')=\tfrac{1}{2}O_2+(S'')+(\vdots Si-O-Si\vdots) \quad \ldots\ldots\ldots\ldots(1)$$

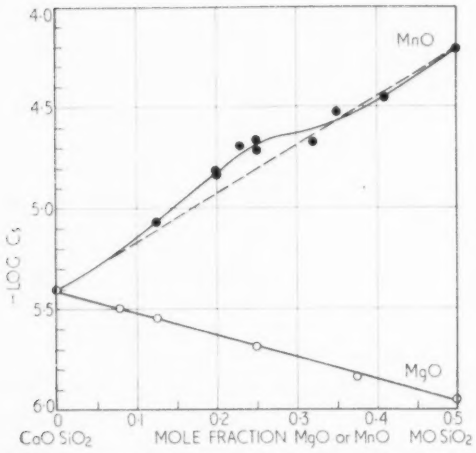
Calculations of metal oxide activities in silicate melts have led to the conclusion[11] that when two metasilicates are mixed, such as MnO.SiO_2+CaO.SiO_2, the process consists of an athermal random mixing of the two different cations in the silicate lattice. If this is so one would expect the heat of reaction[1] to vary linearly as one cation replaces another in the silicate melt, and the entropy to remain unchanged. Thus the free energy change and the logarithm of the equilibrium constant should vary linearly with composition. Figure 6 thus provides support especially in the case CaO.SiO_2+MgO.SiO_2 for the theories of silicate mixing that have already been put forward.[11] This linear relationship is identical with the following equation derived by Flood and Grjotheim[2] for calculating the effect of different cations in a melt, on the equilibrium constant of a reaction in which only the anions take a direct part,

$$\log K=N_X \log K_X+N_Y \log K_Y+\ldots\ldots,$$

where N_X, N_Y etc. are the cation fractions, $n_X/(n_X+n_Y+\text{etc.})$ and K_X, K_Y, etc. are the equilibrium constants, when only cations X, Y, etc. are present. Flood and Grjotheim's equation was, however, arrived at by a thermodynamic argument and the assumption that a large number of terms involving activity coefficients can be neglected. The simple model indicates more clearly what is involved in this assumption.

It is interesting to note that the deviations from the ideal on log C_S observed in the case of MnO.SiO_2+CaO.SiO_2 run parallel with similar deviations from the ideal[3] in the activities of manganese oxide in this same pseudo-binary. Comparison of Figs.2*a* and 2*b* show that the maximum effects occur about half-way across the composition axis and increase with falling temperature. The maximum deviations on C_S are about 30% and

* i.e. $C_S=\dfrac{n_S}{n_{CaO}+n_{MnO}+n_{SiO_2}}\left(\dfrac{p_{S_2}}{p_{O_2}}\right)^{\frac{1}{2}}$



6 *Sulphide capacities (molar) of the pseudo-binaries* $MnO.SiO_2+CaO.SiO_2$ *and* $MgO.SiO_2+CaO.SiO_2$ *at 1650°C*

50% at 1600° and 1500°C respectively, while those on a_{MnO} are about 15% and 25% respectively. It looks as though the high C_S values merely reflect a manganese oxide activity that is higher than 'ideal' in the middle region of the pseudo-binary. The sulphide capacity in this ternary should be closely related to the sum of the manganese oxide and lime activities. The latter being many times smaller than the former at 25 mole-%MnO and the equilibrium constants for the pure phase reactions $MO+\frac{1}{2}S_2=MS+O_2$ being similar,[1] one would expect C_S to follow a_{MnO} closely, provided there are no unexpectedly great differences between the activity coefficients of calcium and manganese sulphides in the mixtures.

ACKNOWLEDGMENT

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ADDENDUM

The gas-slag equilibrium data just published by Kalyanram *et al.*[12] make it possible to calculate sulphide capacities for $CaO+MgO+SiO_2$ mixtures at 1500°C. These have been plotted at constant silica mole fractions as in Fig.4 with $NSiO_2$ ranging from 0·39 to 0·57 and NMgO from 0 to 0·32. Within the consistency of the results a good series of straight lines is obtained; the slope $d \log C_S/d N_{MgO}$ changes little with $NSiO_2$: it is equal to −1·5 and hence rather greater than the value of −1·0 found in Fig.4 for 1650°C.

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Sulphide capacities of silicate melts

PART II

K. P. Abraham and F. D. Richardson

FOLLOWING PREVIOUS WORK on the sulphide capacities of binary and ternary silicate and aluminate slags[1–3] this paper presents results that have been obtained for a number of slags containing phosphorus pentoxide, and for slags in the system $CaO+MgO+SiO_2+Al_2O_3$.

The measurements were made by bringing slags into equilibrium with gas mixtures made from $H_2+CO_2+SO_2$ mixed in the proportions required to give the desired partial pressures of oxygen and sulphur at the equilibrium temperature. The technique employed was virtually the same as that reported previously.[3]

The thermodynamic data relating to the gaseous species CO, CO_2, H_2, H_2O, H_2S, COS, SO, and S were the same as used elsewhere.[3] The data for SO, HS, and S are slightly different from those on which the sulphur capacities reported by Fincham and Richardson[1] were based; their values have therefore been recalculated, together with those reported by other authors.[4]

SYNOPSIS

Sulphide capacities, wt-%S $(p_{O2}/p_{S2})^{\frac{1}{2}}$, have been measured at 1650°C for a number of slags in the systems $CaO+P_2O_5$, $CaO+P_2O_5+SiO_2$, $CaO+P_2O_5+Al_2O_3$. The results show that P_2O_5 is very much more effective than silica or alumina, mole for mole, in lowering sulphide capacities. Corresponding measurements at 1500°C with the quaternary $CaO+MgO+SiO_2+Al_2O_3$, useful as a slag for the iron blast-furnace, show that sulphide capacities greater than those of normal blast-furnace slags can be obtained.

On account of changes in the thermodynamic data for gases containing sulphur, sulphide capacities previously published for the systems $CaO+SiO_2$, $CaO+Al_2O_3$, $CaO+SiO_2+Al_2O_3$, have been recalculated and all the currently available data are given in appropriate diagrams. The changes do not invalidate the general conclusions that had previously been drawn concerning sulphur in silicate melts. 1874

EXPERIMENTAL

The technique differed from that described previously[1] only in the following aspects:

Materials

The phosphate was introduced into the slags by adding the appropriate amounts of calcium meta- or pyrophosphate. The metaphosphate was prepared by recrystallizing $Ca(H_2PO_4)_2H_2O$ from phosphoric acid solution, dehydrating by stages at 250° and 400°C, and finally heating to constant weight at 750°C. The pyrophosphate was BDH material ignited for 1 h at 1000°C. Analysis of both products indicated that the compositions were correct to ±1%.

Analysis for phosphate

Slag samples of about 0·1 g were dissolved in 20 ml of 1:1 nitric acid and boiled for 2–3 h to convert meta- and pyrophosphates into the orthophosphate.[5] The orthophosphate was precipitated with excess of ammonium molybdate and estimated volumetrically with carbonate free sodium hydroxide.[6] Slags which contained silica were first treated with a mixture of nitric acid and hydrofluoric acid and evaporated to dryness to expel silicon tetrafluoride. The residues were dissolved in nitric acid and phosphorus was estimated as described above.

RESULTS

Two difficulties were experienced in experiments with slags which contained more than 0·3 mole fraction of P_2O_5 in the binary $CaO+P_2O_5$. At 1650°C with oxygen partial pressures less than 10^{-8} atm, the maximum for a satisfactory pick-up of sulphur, so much phosphorus alloyed with the platinum cups that they melted. Iridium cups were tried and were quite satisfactory but no quantitative results could be obtained with such slags: this was because the P_2O_5 volatilized rapidly in the gas stream, and the mole fractions of P_2O_5 always fell to about 0·30 during an experiment. On account of this, measurements could not be made with $CaO+P_2O_5$ mixtures containing more than 0·27 mole fraction P_2O_5; this fact combined with the high melting points of $3CaO.P_2O_5$ and CaO prevented more than two compositions from being studied in the binary. With the $CaO+SiO_2+P_2O_5$ and $CaO+Al_2O_3+P_2O_5$ mixtures, 0·07 mole fraction of P_2O_5 was

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TABLE I Slags containing phosphate

Slag composition, wt-% CaO	P_2O_5	SiO_2	Al_2O_3	C_S, wt-% 1650°C	No. of samples	Scatter
52·4	47·6	...	...	$1·03\times10^{-4}$	3	±6%
58·0	42·0	...	...	$1·55\times10^{-3}$	4	±4%
57·8	15·0	27·2	...	$3·96\times10^{-4}$	4	±5%
50·5	15·0	34·5	...	$1·81\times10^{-4}$	4	±5%
54·2	12·8	...	33·0	$5·00\times10^{-3}$	4	±4%
43·7	12·0	...	44·3	$1·02\times10^{-3}$	4	±5%
60·0	13·2	...	26·8	$1·17\times10^{-2}$	3	±3%

the maximum that could be retained satisfactorily during the course of an experiment. For the slags for which quantitative results are given, no losses of P_2O_5 could be detected by weighing, and check analyses with the slags $CaO+P_2O_5$ and $CaO+SiO_2+P_2O_5$ showed that there were no serious losses of phosphorus to the platinum.

The results for the slags containing phosphate are given in Table I. Those for the quaternary are given in Table II.

DISCUSSION

Slags containing P_2O_5

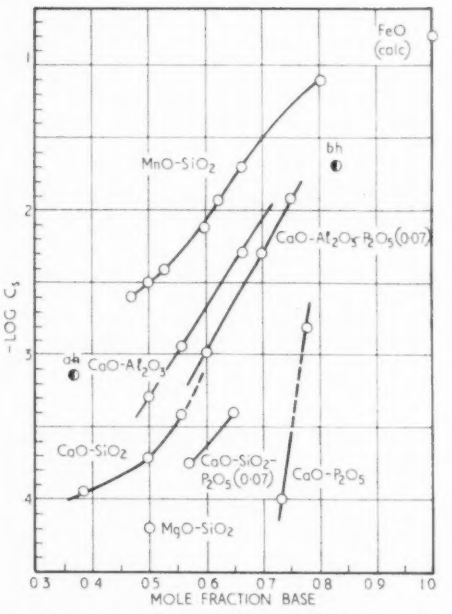
Results for the slags containing P_2O_5 are shown in Fig.1, where they may be compared with previous measurements made at 1650°C[1, 2] on $MnO+SiO_2$, $CaO+SiO_2$, $CaO+Al_2O_3$, and $MgO+SiO_2$. Where necessary the previous C_S values have been corrected for the changes which have occurred since 1954, in the thermodynamic data for SO, and S and hence HS. It is evident that on a mole for mole basis, the addition of P_2O_5 to lime leads to much lower sulphide capacities than the addition of Al_2O_3 or SiO_2. This is to be expected because the heats of formation of phosphate melts from the component oxides, are much more negative than those of silicate and aluminate melts, and the corresponding metal oxide activities must be very much less.

The influence of P_2O_5 on the sulphide capacities of slags containing CaO, Al_2O_3, and SiO_2 can best be appreciated by reference to Figs.2*a–c* where the C_S contours have been constructed with the aid of appropriate interpolation and sometimes extrapolation of the results shown in Fig.1. In the region investigated the substitution of phosphorus pentoxide for silica or alumina lowers the sulphide capacities very much, the effect being greater with SiO_2 than with Al_2O_3. Alumina and phosphorus pentoxide when mixed in equimolar proportions, are structurally identical with silica[7] and the compound $Al_2O_3.P_2O_5$ has about the same heat of formation from its elements as $4SiO_2$.* It is thus of interest to see whether a mole of P_2O_5 and one of Al_2O_3 are together equivalent to four moles of SiO_2 in their effect on sulphide capacities, and hence

* $Al_2O_3+P_2O_5=2AlPO_4$, $\Delta H_{298°K}=-82·1$ kcal.

TABLE II Quaternary slags

Slag composition, wt-% Al_2O_3	CaO	MgO	SiO_2	C_S, wt-% 1500°C	No. of samples	Scatter
15·0	43·0	12·0	30·0	$5·43\times10^{-4}$	5	±3%
20·0	43·0	12·0	25·0	$6·85\times10^{-4}$	4	±4%
25·0	45·0	10·0	20·0	$8·92\times10^{-4}$	4	±4%
30·0	56·0	5·0	9·0	$3·97\times10^{-3}$	5	±5%



1 *The sulphide capacities of melts at 1650°C;* **ah** *acid open-hearth,* **bh** *basic open-hearth from Fincham and Richardson*[2]

on the ratio $aCaO/\gamma CaS$. It can be seen from Fig.1 that the slag CaO 0·60, Al_2O_3 0·33, P_2O_5 0·07 has a C_S value of 10^{-3}. If the suggested equivalence exists, this should have the same sulphide capacity as the slag CaO 0·52, SiO_2 0·25, Al_2O_3 0·23, because the atomic weight of silicon is almost the mean of those of alumina and phosphorus. From Fig.2*c* the C_S value for the latter slag is about $1·1\times10^{-3}$, so in this case $P_2O_5+Al_2O_3$ is about as effective in lowering C_S and metal oxide activities as $4SiO_2$. Correspondingly one finds that C_S values for the other similar pairs of slags listed in the upper part of Table III are about equal. However, the pairs listed in the lower part of Table III show that the C_S values for slags which contain equimolar proportions of Al_2O_3 and P_2O_5 in the absence of silica (estimate from Fig.2*b*) are higher than those for the equivalent $CaO+SiO_2$ melts. In these cases a mole of Al_2O_3 and a mole of P_2O_5 are together more nearly equivalent to three moles of silica. It is noticeable from Fig.1 that the substitution of P_2O_5 for Al_2O_3 lowers the C_S values much less than the substitution of P_2O_5 for SiO_2. This is to be expected from the large

TABLE III C_S values for slags

Slag composition mole fractions CaO	Al_2O_3	P_2O_5	SiO_2	$C_S\times10^4$
0·60	0·33	0·07	...	10
0·52	0·23	...	0·25	11
0·65	0·28	0·07	...	22
0·57	0·18	...	0·25	30
0·70	0·23	0·07	...	45
0·61	0·14	...	0·25	40
0·65	17·5	17·5	...	2
0·48	...	...	0·52	1·7
0·69	15·5	15·5	...	10
0·53	...	...	0·47	2·5
0·71	14·5	14·5	...	15
0·55	...	...	0·45	3·3

negative energy of interaction between P_2O_5 and Al_2O_3.* The effect might be exploited in practice.

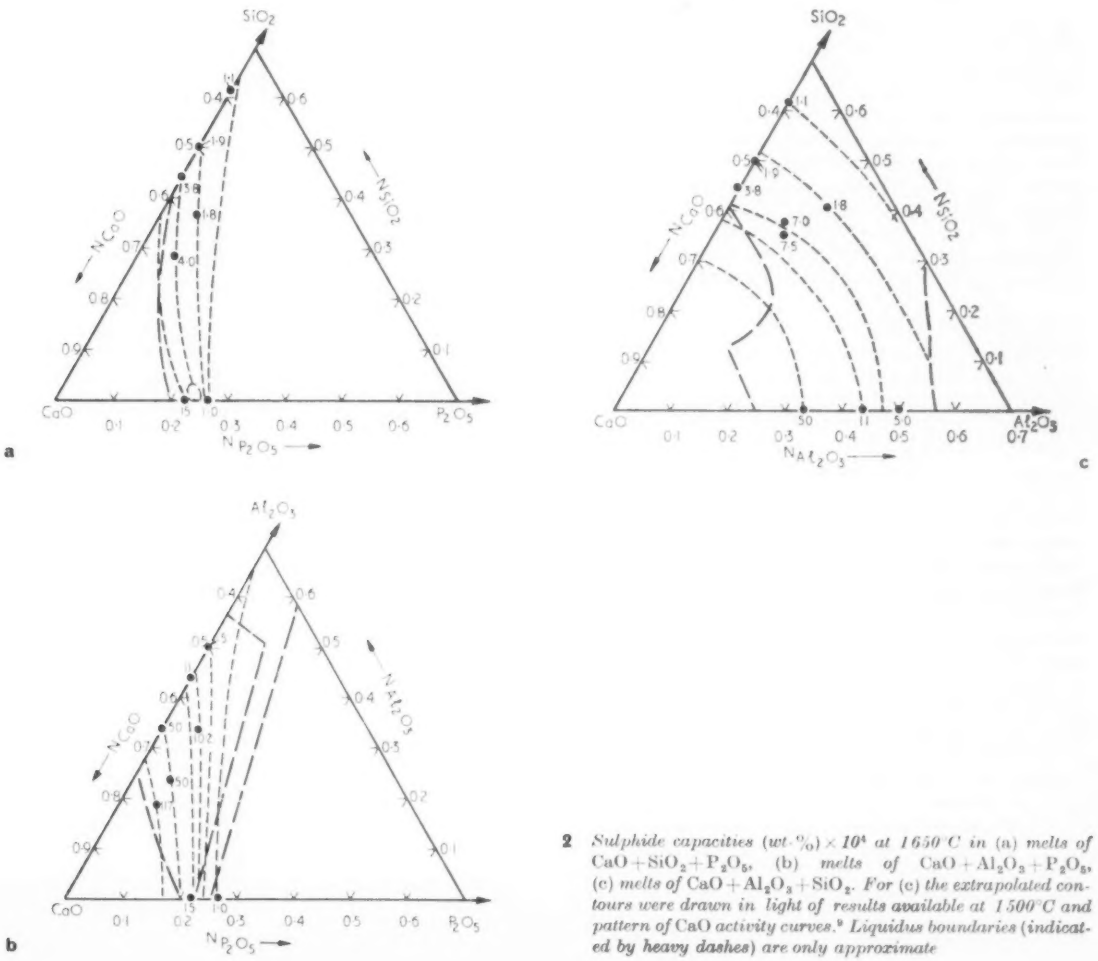
CaO + MgO + Al_2O_3 + SiO_2 melts

The results obtained for these melts at 1500°C can best be appreciated by reference to the data available for the ternary $CaO+SiO_2+Al_2O_3$ at this same temperature. It is possible to construct the pattern of C_S values shown for this system in Fig.3 by reference to the previous measurements that have been made at 1500°C for $CaO+SiO_2$, $CaO+Al_2O_3$ (*see* Fig.4), and mixtures of the two,†[2] allowance being made for the new gas equilibrium data.[8] The extrapolation of the C_S contours has been made in the light of the pattern of CaO activities established for 1500°C–1700°C in this system by Chipman.[9] The filled circles in the left-hand corner of the diagram represent the results for the slags in Table II. It appears that the substitution of MgO for CaO (mole for mole) leads, as one would expect from Fig.1, to lower sulphide capacities: the advantage of carrying MgO in slag is that it is possible to obtain slags that are fluid at 1500°C in spite of the high concentration of metal oxides which give the high sulphide capacities. Osborn *et al.*[10] have determined the liquidus for such slags and have advocated their use in ironmaking. They state, however, that the sulphur partitions that can be attained with them (i.e. their sulphide capacities) are determined solely by the wt-% ratio $(CaO+MgO)/(SiO_2+Al_2O_3)$ and that provided this is constant, the capacities are unaffected by the alumina content. This is clearly at variance with the results in Table II. For the first three slags this ratio is constant, yet there is an improvement of almost 70% in the C_S values as 10% alumina replaces silica, weight for weight. This is what one might expect from the general pattern of C_S values for melts containing Al_2O_3, SiO_2, or both.

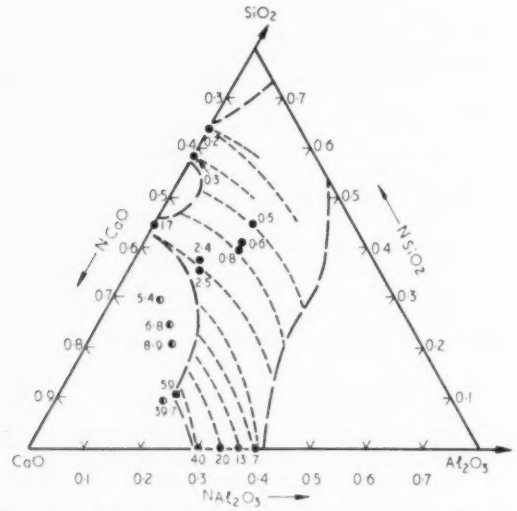
Burgess and Baldwin[11] have shown that these high magnesia slags give better sulphur partitions in the iron blast-furnace than those normally used. For instance, the partition ratios obtained in practice with the first of the slags listed in Table II, are four times better than those normally obtained with a more usual slag, such as CaO 44 wt-%, MgO 3, SiO_2 33, Al_2O_3 20

* $Al_2O_3+P_2O_5=2AlPO_4$, $\Delta H_{298°K}=82{\cdot}1$ kcal.

† The results that have just become available from the work of Kalyanram *et al.*[19] are in good agreement with the contours in Fig.3. They have not been plotted as they lie mainly in the region CaO 0·35–0·55, Al_2O_3 0·02–0·20.



2 *Sulphide capacities (wt-%) × 10⁴ at 1650°C in* (a) *melts of* $CaO+SiO_2+P_2O_5$, (b) *melts of* $CaO+Al_2O_3+P_2O_5$, (c) *melts of* $CaO+Al_2O_3+SiO_2$. *For* (c) *the extrapolated contours were drawn in light of results available at 1500°C and pattern of* CaO *activity curves.*[9] *Liquidus boundaries (indicated by heavy dashes) are only approximate*



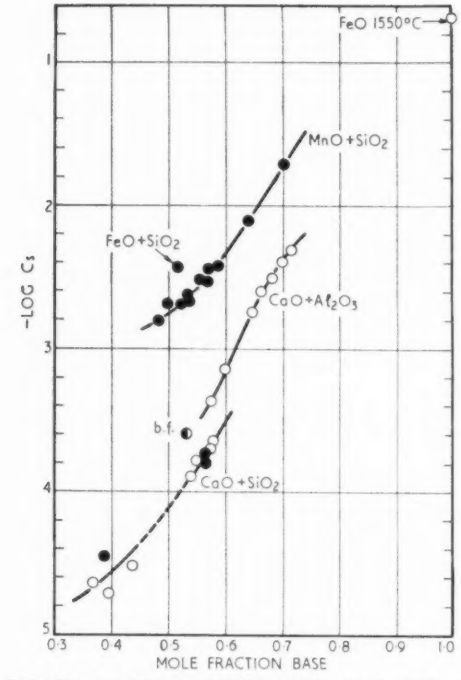
3 *Sulphide capacities (wt-%) $\times 10^{-4}$ at 1500°C in melts of* $CaO+Al_2O_3+SiO_2$. *Pied circles are for slags containing* MgO *from Table II,* NMgO *being added to* NCaO *in order to plot them; square, Carter and Macfarlane*[4]

(C_S $2{\cdot}52\times10^{-4}$ at 1500°C). The values of (S)/[S] are about 100 instead of the usual 25. The sulphide capacity of the slag containing magnesia is only about twice that of the more usual slag, so other factors must be contributing to the improved partition obtained in practice. Higher temperatures of slag and metal may have caused part of the difference, but it seems more likely that, with the high magnesia slags, the equilibrium distributions of sulphur between slag and metal are more closely approached because of lower viscosities. For the two slags just compared the viscosities at 1500°C are 2·1 and 3·8 poise respectively.[12]

Previous work at 1500°C

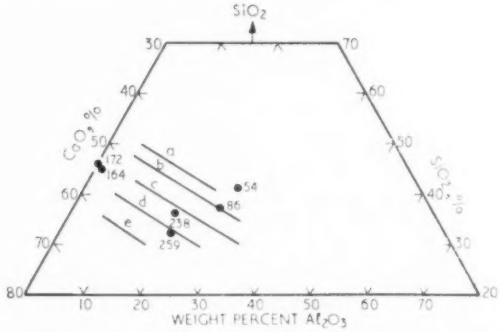
Sulphide capacities have been measured at 1500°C by Carter and Macfarlane[4] for $CaO+Al_2O_3$, $CaO+SiO_2$, and by Fincham and Richardson[1] for $CaO+SiO_2$ and $FeO+SiO_2$. Their published C_S values have been corrected in the light of the newer gas equilibrium data and the new values are shown in Fig.4, which also includes those for $MnO+SiO_2$.[3] The agreement between the two sets of results for $CaO+SiO_2$ is very satisfactory: it confirms to some extent the new gas equilibrium data for SO, S, and HS because Carter and Macfarlane used mixtures of $CO+CO_2+SO_2$ whereas Fincham and Richardson[1] used $H_2+CO_2+SO_2$. The calculations for the sulphur and oxygen partial pressures developed in the gas mixtures used by these workers and by the authors, are complex and lengthy unless done by computer. For this reason the compositions and the partial pressures of oxygen and sulphur are listed in the Appendix for the benefit of subsequent workers. (For free energy equations used see Part I.[3])

It is possible to compare the revised sulphide capacities for $CaO+SiO_2+Al_2O_3$ melts with the sulphur partition measurements made by Hatch and Chipman[14] at 1500°C with the system slag+iron+graphite. This is done in Fig.5 which shows the values in weight percent, of the ratio (S)/[S] for iron in equilibrium with the $CaO+SiO_2+Al_2O_3$ slags. Although



4 *Sulphide capacities at 1500°C for* $CaO+Al_2O_3$, $CaO+SiO_2$, $FeO+SiO_2$, *and* $MnO+SiO_2$ *melts. Open circles Carter and Macfarlane;*[4] *closed circles Abraham,*[3] *Fincham,*[2] *and Richardson; pied circle blast-furnace slag;*[2] FeO *at 1550°C from St Pierre and Chipman*[13]

Hatch and Chipman sometimes carried substantial amounts of magnesia in their slags because they used magnesia crucibles, their results, when the magnesia was between 0·1 and 5 wt-%, are in good agreement with the lower contours in their Fig.10: their standard deviation is substantial (about 20%), probably on account of the fact that they did not always reach equilibrium with respect to the partition of silicon between slag and metal. The points in Fig.5 show the values of (S)/[S] calculated for the conditions of Hatch and Chipman by combining the revised sulphide capacities with the established thermodynamic data for the formation of H_2S[15] and CO,[16] for sulphur in iron[17]



5 *Values of* (S)/[S] *in wt-% for* $CaO+SiO_2+Al_2O_3$ *slags in equilibrium with carbon saturated iron at 1500°C. Contour lines from Hatch and Chipman*[13]*:* (a) *75;* (b) *100;* (c) *150;* (d) *210;* (e) *300; filled circles from revised sulphide capacities*

and for the effect of carbon and silicon on the dissolved sulphur.[18] Agreement is now more satisfactory than hitherto, and within the error limits in view of all the data involved in the calculations.

ACKNOWLEDGMENTS

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APPENDIX

Compositions and partial pressures of oxygen and sulphur

Temperature, °C	Ingoing gas p_{CO}/p_{CO_2}	p_{SO_2}	Calculated pressures at temperature $p_{O_2} \times 10^9$	$p_{S_2} \times 10^4$
1500	1·52	0·0080	12·7	12·6
1500	1·49	0·0072	13·0	10·6
1500	1·52	0·0083	12·8	13·3
1500	1·06	0·0072	25·3	5·66
1500	1·51	0·0030	11·8	2·76
1500	1·50	0·0083	13·1	13·1
1500	1·50	0·0086	13·2	13·8
1500	3·22	0·0095	3·14	27·0
1500	1·49	0·0085	13·3	13·4
1500	1·51	0·0078	12·8	12·1
1500	1·52	0·0077	12·7	12·0
1500	3·67	0·0308	4·28	110·0
1500	3·69	0·0302	4·18	108·0
1500	3·71	0·0290	4·01	103·0
1500	3·62	0·0311	4·40	111·0
1500	4·70	0·0341	3·16	129·0
1500	1·51	0·0082	12·9	13·0
1500	4·53	0·0313	3·09	117·0
1500	1·55	0·0084	12·3	13·9
1500	1·49	0·0084	13·3	13·2
1500	1·47	0·0082	13·6	12·5

Temp., °C	Ingoing gas p_{CO_2}	p_{H_2}	p_{SO_2}	p_{N_2}	Calculated pressures at temperature p_{O_2}	p_{S_2}
1650	0·135	0·355	0·010	0·500	$1·02 \times 10^{-8}$	$9·70 \times 10^{-4}$
1650	0·333	0·157	0·010	0·500	$1·07 \times 10^{-6}$	$5·01 \times 10^{-5}$
1650	0·116	0·364	0·020	0·500	$1·04 \times 10^{-8}$	$2·96 \times 10^{-4}$
1650	0·220	0·260	0·020	0·500	$1·11 \times 10^{-7}$	$2·71 \times 10^{-5}$
1650	0·326	0·154	0·020	0·500	$1·12 \times 10^{-6}$	$1·84 \times 10^{-4}$
1575	0·271	0·209	0·020	0·500	$8·90 \times 10^{-8}$	$1·87 \times 10^{-3}$
1575	0·374	0·106	0·020	0·500	$9·92 \times 10^{-7}$	$4·34 \times 10^{-5}$
1500	0·382	0·115	0·003	0·500	$1·82 \times 10^{-7}$	$3·87 \times 10^{-6}$
1500	0·346	0·134	0·020	0·500	$1·07 \times 10^{-7}$	$4·26 \times 10^{-4}$
1500	0·329	0·151	0·020	0·500	$7·25 \times 10^{-8}$	$7·84 \times 10^{-4}$
1500	0·115	0·375	0·010	0·500	$4·19 \times 10^{-10}$	$5·86 \times 10^{-4}$
1500	0·034	0·456	0·010	0·500	$3·06 \times 10^{-11}$	$2·94 \times 10^{-4}$
1500	0·054	0·436	0·010	0·500	$6·83 \times 10^{-11}$	$3·45 \times 10^{-4}$
1500	0·163	0·327	0·010	0·500	$1·38 \times 10^{-9}$	$8·93 \times 10^{-4}$
1500	0·280	0·210	0·010	0·500	$1·93 \times 10^{-8}$	$9·35 \times 10^{-4}$
1500	0·306	0·184	0·010	0·500	$3·38 \times 10^{-8}$	$5·85 \times 10^{-4}$
1500	0·408	0·082	0·010	0·500	$4·77 \times 10^{-7}$	$6·69 \times 10^{-6}$
1500	0·116	0·364	0·020	0·500	$7·28 \times 10^{-10}$	$2·29 \times 10^{-2}$
1500	0·240	0·240	0·020	0·500	$1·21 \times 10^{-8}$	$3·40 \times 10^{-3}$
1500	0·320	0·160	0·020	0·500	$5·97 \times 10^{-8}$	$1·03 \times 10^{-3}$
1500	0·356	0·124	0·020	0·500	$1·37 \times 10^{-7}$	$2·80 \times 10^{-4}$
1500	0·369	0·111	0·020	0·500	$1·92 \times 10^{-7}$	$1·52 \times 10^{-4}$
1500	0·417	0·063	0·020	0·500	$9·17 \times 10^{-7}$	$7·41 \times 10^{-5}$
1500	0·471	0·0094	0·020	0·500	$6·93 \times 10^{-5}$	$1·35 \times 10^{-7}$
1500	0·475	0·0047	0·020	0·500	$2·32 \times 10^{-4}$	$1·21 \times 10^{-10}$

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THE IRON AND STEEL ENGINEERS GROUP

The physics of oxygen steelmaking

C. Holden and A. Hogg

SYNOPSIS

An attempt has been made to analyse the factors controlling the process of mass transfer in oxygen steelmaking. Theoretical and model studies have been used to try to explain some of the practical observations which have been made. It is concluded that the main barrier to oxygen transfer is in the metal and that optimum efficiencies can only be achieved by either stirring the metal or injecting the oxygen uniformly through the melt.

1887

INTRODUCTION

IT HAS BECOME increasingly evident during recent years that the degree to which the slag and metal are mixed is a controlling factor in steelmaking. To some extent the steelmaking process creates its own mixing, the bubbles of CO formed from the reactions of oxides with carbon creating local turbulence and enhancing the reactions between slag and metal. Unfortunately in many cases the degree of mixing achieved in this way is insufficient. Several methods of mechanical mixing have been used ranging from the use of simple hand rabbles to complex engineering designs for shaking or rotating the whole steelmaking vessel. In the Bessemer converter good mixing is obtained from the high degree of turbulence created by the passage of a large volume of gas through the charge, while in top-blowing the jet can be regarded as the effective bath agitator. In the open-hearth furnace too, the high-velocity flame helps in the mixing of the slag and metal, and this may partially explain why, although calculations show that the use of high steam/oil ratios reduces radiation heat transfer and should therefore reduce production rate, the reverse is found. In the electric-arc furnace the deep bath and the absence of a jet or flame make mixing more difficult, with the result that some plants have installed electrical induction stirrers, while in recent years bath lancing with oxygen has been increasingly applied.

THE USE OF OXYGEN IN STEELMAKING

The OH furnace

The majority of the published work on decarburization in the OH furnace with oxygen is concerned with lancing of the bath through uncooled steel pipes. The size of pipe used varies somewhat but 1 in. dia. seems the most popular. This is probably a compromise, as smaller pipes are mechanically unsound, and larger pipes tend to burn away quickly. The pressure available at the end of the lance depends on the previous pipework but a figure of 120 lb/in^2 appears to be typical. The flow rate used varies considerably from plant to plant. In most cases the maximum flow rate used is limited by the splash and fume produced and bears no obvious relation to furnace capacity. A figure of about 30000 ft^3/h through each lance used is very common.

As regards jetting on to the surface of the bath, the rates of flow and pressures available are of the same order. Supersonic nozzles have been used but there is no evidence that they are superior to submerged lances.

The superiority of one method of introducing oxygen over the other can be assessed on carbon removal rate, specific oxygen consumption, loss of yield, and refractory wear.

Carbon removal and oxygen consumption

It is difficult to separate the two factors, rate of carbon removal and specific oxygen consumption, as there is rarely sufficient information available about other

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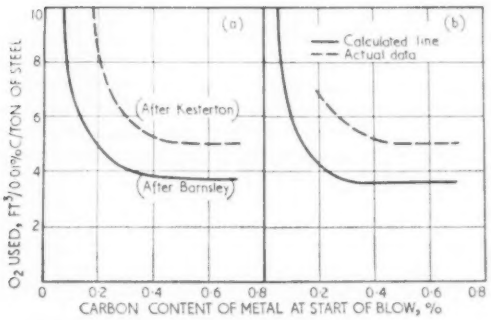


a Abbey OH furnace: water-cooled jet
b SP and T 5-ton arc furnace: uncooled immersed lance

1 *Comparison of calculated and actual specific oxygen consumption for two methods of oxygen blowing*

sources of oxygen, e.g. furnace atmosphere, charged ore, etc. However, the following principles have been abstracted:

(1) For high carbon removal rates and low specific oxygen consumptions it is essential that the lance be positioned below the slag surface or, in the case of jetting, the slag surface blown away to expose metal. Thus direct contact between metal and oxygen is essential for fast reaction.

(2) If the oxygen flow rate is increased then the carbon removal rate is increased, and the oxygen consumption per point of carbon removed generally decreases. However, there is evidence to suggest that with a given submerged lance size there is a critical flow rate beyond which the specific oxygen consumption increases. This may mean that as far as oxygen efficiency is concerned there is an optimum blowing rate for submerged lances which varies with lance size. If the optimum has been reached with a particular size of lance then an increase in flow rate must be accompanied by an increase in lance size. No data have been found of an optimum blowing rate for a given lance size when jetting.

(3) As the carbon content of the bath decreases, then for a given flow rate of oxygen the rate of decarburization decreases, so that the oxygen consumption referred to carbon removed increases (Fig.1). Because the equilibrium conditions require a high oxygen content of the metal and slag at low carbons, then for a 100% efficient process the oxygen consumption referred to carbon removal should increase. It can be seen in Fig.1 that the theoretical curve[1,2] calculated on the basis of equilibrium data is of a similar shape to the practical curve.

(4) The problem of lance design does not appear to have been adequately explored. However, it is claimed by a number of workers that the use of multiple lances has decreased the oxygen consumption. There is also a tendency to believe that surface jetting is less efficient than submerged lancing.

(5) Blowing with air or nitrogen gives an increase in carbon oxidation rate. Some workers claim that above about 0·25%C in the bath, air is as good as oxygen as a decarburizer but below this value oxygen is the better. The most interesting results, however, are those of Warren[3] who reported the following:

Gas used	Carbon at start, %	Carbon drop, min., %	Carbon at start, %	Carbon drop, min., %
Oxygen	1·20	0·014	0·70	0·120
Dry air	1·20	0·012	0·70	0·009
Nitrogen	1·20	0·009	0·70	0·007
Normal practice	1·20	0·005	0·70	0·005

(6) As nitrogen increases the decarburization rate, an oxygen jet must have some physical as well as chemical effect on the bath. This argument is reinforced by the fact that at high carbon contents the oxygen consumption is often less than theoretical. For example, theoretically the oxygen required to remove 1 point of carbon per ton of steel is about 3·4 ft^3 whereas values of as low as 2 ft^3 are reported when the rate of carbon removal is more than double that of normal practice.

Loss in yield

Oxygen decarburization leads, if anything, to a loss in yield. However, many people have claimed that the melt is much nearer equilibrium on tapping and that the iron content of the slag, particularly for low-carbon melts, is lowered.

Refractory wear

There is no doubt that refractory wear is increased, but the extent is difficult to assess. Jetting gives more fume and splash than lancing, but withdrawing the jet from the slag surface reduces refractory wear. Multiple-hole lances also decrease splash.

In lancing, too shallow a lance angle can cause violent splashing, and a water-cooled lance, according to some Soviet workers,[4] gives twice as much fume as an uncooled lance. The use of air as a decarburizer tends to give less fume but more splash than oxygen. Finally, it has been generally observed that the rate of fume evolution is dependent on the carbon content of the bath.

Electric arc furnace

Both lancing and jetting have been applied in arc furnaces, but in the case of the stainless steels the object of oxidizing the carbon quickly is to obtain a high temperature so that oxidation of chromium is retarded. However, the results reported as regards oxygen efficiency agree with those reported for OH practice, in that at low flows submerged lancing is more efficient than surface jetting and there is an optimum flow rate through a given lance size, on either side of which oxygen consumption increases.

Other interesting points which emerge are: (i) induction stirring of the bath helps to promote the boil by equalizing the temperature of the bath, but no claim is made as to any increase in oxidation rate once the boil has started; (ii) the use of compressed air to stir the bath gives little or no increase in oxidation rate.

It would seem that in the electric furnace, stirring has not such a pronounced effect on oxidation rate.

Bottom-blown converters

In the Bessemer, or Thomas, converter, air, air+oxygen, steam+oxygen, or CO_2+oxygen, are blown at pressures of 20–30 lb/in² through a series of holes underneath the charge. In the Thomas process 1·5%P is required, but with 35%O enrichment, irons with phosphorus contents down to 1% can be worked. In

the acid, or Bessemer process, the silicon content is usually in excess of 1·25%, but again the use of oxygen enrichment allows the process to operate with silicon contents of well below this figure.

Conversion rates are extremely high, being up to 4 tons/min in 50-ton converters. The temperature of the blowing gas is normally 150–200°C but in the Warnant process, coke-oven gas is burned with oxygen in a combustion chamber to give a blast temperature of 250°C.

Oxygen/steam

This is normally used in the ratio O_2/H_2O of 45/55 by volume, and as about 70% dissociation of steam occurs the blast contains about 65% of oxygen. Owing to the high proportion of oxygen it is stated that the blowing area (no. of tuyeres × cross-sectional area) must be reduced to about half of that of normal bottom-blown converters to keep the process under control. If oxygen/steam is blown throughout, then oxygen consumption is 2000–2100 ft³/ton. Some plants prefer to use oxygen/air followed by oxygen/steam, and in this case consumption of pure oxygen is reduced to about 1800 ft³/ton.

Design of vessel

If air alone is used, one of the disadvantages of bottom-blown steel is its nitrogen content. It is claimed that this can be reduced by reducing the path length of the air through the charge, i.e. by using shallower baths or by side-blowing.

Kootz and Gille[5] state that secondary oxidation of carbon during the late refining period by FeO formed earlier in the process gives rise to an increased CO evolution at this time. This carries away with it some of the nitrogen so that even when blowing with air the nitrogen content of the bath can be reduced during this period. They also state that the design of converter can determine the proportion of direct to indirect oxidation, and have used arrangements of tuyeres which were concentrated at one part of the bottom and permitted to immerse only a little. This effectively increased the amount of secondary oxidation and reduced the final N_2 content of the steel. They claimed that 'slopping' and N_2 pickup could be satisfactorily simulated in small-scale models. Their model experiments showed that pickup of N_2 was not influenced by bath oscillation. A further conclusion was that the depth of the bath had a pronounced effect on the degree to which the charge oscillated. The movement of the charge increased with the proportion of slag entrained in the metal, but dry unwettable lime which could float on the surface tended to calm down the oscillations.

Leroy[6] made an extensive study of bottom-blown converters by means of water models and concluded that as regards the effect of shape on limiting blast the results were in good agreement with those obtained on full scale plant. For a given converter he found that there was an optimum number of tuyeres for a given diameter of bottom plate, and that the limiting blast rate was about proportional to the height of the lining. As far as flow within the bath was concerned, he concluded that circulation within the outer part of the vessel was undesirable. To reduce this he suggests that the bottom size should be a maximum, and the tuyeres should be placed as near as possible to the edge.

LD process

Despite the phenomenal success the LD process has enjoyed all over the world since the first commercial units were put into operation at Linz and Donawitz in 1952–1953, little has been published on the influence of the hydrodynamics within the bath on oxygen transfer. Some of the more general characteristics of the process are given below:

(i) oxygen efficiency is generally very high, about 95%, but drops off at low oxygen flow rates even when the slag is penetrated, suggesting that it is necessary to maintain a certain turbulence level in the bath

(ii) oxygen must be sufficiently pure in order to give a finished steel with low nitrogen content

(iii) the rate of refining is high, the highest achieved to date being four tons/min

(iv) the nozzle is usually of the Laval type and the oxygen pressure just before this is usually in excess of 100 lb/in² and can be as high as 180 lb/in²

(v) the position of the lance relative to the bath appears to be very important, the general opinion being that the oxygen must be blown at the centre of the bath with the lance absolutely vertical to spare the refractory lining

(vi) vessel shape also appears to play an important part in bath circulation

(vii) phosphorus content in the hot metal generally governs the variation in practice. A high phosphorus content charge requires either double slagging or extended blowing. Early formation of a reactive slag is considered essential for dephosphorization.

Two theories regarding the principal method of decarburization have been proposed for the LD process.

Hauttmann[7] considers that the oxygen reacts with iron at the point of impact of the jet to form ferrous oxide which is then circulated through the bulk of the bath, reacting with carbon all the time, by currents initiated by differences in density. These circulation currents also carry fresh metal to the slag/metal interface where removal of the non-metallics takes place.

However, on the strength of pilot and large-scale experiments, Hammer[8] proposes that refining takes place largely in the gas phase immediately above the bath. It was observed that deep penetration of the melt by the jet was not possible but at a certain critical velocity small droplets are formed and carried by the deflected jet stream into the atmosphere above the bath. These are oxidized, and on falling back into the bath, transfer the oxygen to it.

The common point in the two theories is the suggestion that ferrous oxide acts as an oxygen carrier. However, more extensive experimental work is necessary before the validity of either is established.

The Oberhausen rotor

In this process the vessel is rotated at a speed of about ½ rev/min not for any hydrodynamic reason but as an attempt to reduce refractory wear by cooling the area previously exposed to the intense action of hot gases loaded with iron oxide. Two water-cooled lances are used, one primary beneath, and one secondary above the slag surface. Oxygen greater than 99% purity is used in the primary lance and 70–90% purity oxygen

is used in the secondary lance. The function of the latter is to burn the CO evolved from the bath to give full utilization of the exothermic reactions. About four times the flow is used in the secondary as in the primary jet (35000 ft³/h). Oxygen consumption has been estimated as about 90% efficient when an allowance is made for the oxygen charged in the ore.

It is postulated by Oberhausen that the agitation of the bath caused by the primary jet is essential for refining. They also state that the evolution of CO from the bath causes splashing of metal and hence direct oxidation from the secondary oxygen stream.

The amount of CO in the waste gas is used as a means of control. It has been found that at low depths of immersion of the primary jet (6 in.) the CO content of the waste gases is nil. As the lance is pushed further into the bath the CO content increases and reaches a maximum at about 12 in. Further experiments have shown that keeping the lance position fixed and increasing the flow rate gives an increase in the CO content of the waste gases up to a flow rate of 44000 ft³/h. Their experiments did not go beyond this point.

The observations regarding the importance of stirring, flow rate, and criticallity of lance position are similar to those found in data on lancing in OH furnaces.

The Kaldo converter

The Kaldo converter is probably the first steelmaking process which has as its main design feature the rapid mixing of the slag and metal. During the initial trials a vessel was used which could be rotated at speeds up to 40 rev/min. However, these tests showed that a maximum speed of 30 rev/min was sufficient and the larger units have been subsequently built with this as their top speed. The strong stirring action induced by the rapid rotation of the vessel ensures a uniform distribution of temperature within the melt, and on the vessel walls and minimizes iron loss due to evaporation. It also enables the iron oxide content of the slag to be reduced to a minimum. Because of the high speed of rotation, agitation of the bath by the oxygen jet is not so necessary and the oxygen lance therefore extends only a short way into the vessel, while the oxygen is supplied at a pressure of only 45 lb/in² gauge. In order to suppress fuming, about 1 gal of water per 1000 ft³ oxygen is added to the oxygen. Because of the high degree of mixing the process is virtually independent of hot metal analysis. However, Swedish operation is based on the use of iron with a phosphorus content of about 2% and a carbon content of about 3·5%. An average yield of 92% with a nitrogen content of only 0·002% and an oxygen consumption of 2300–2500 ft³/ton are claimed. Apart from the obvious engineering difficulties the process approaches the ideal, combining maximum turbulence with the simplicity of top blowing.

Ajax

The vessels in many ways resemble the tilting furnaces from which they were converted: they are fitted with checkers, slag pockets, and means of reversal, and are also provided with burners so that when making carbon steel the charge can be finished under a normal fuel flame. The advantages of using hot air to burn the CO evolved from the bath are that it reduces the oxygen consumption and also helps to dissipate the intense reactions from immediately above the lance over a larger area of the hearth. It is not a true lancing process, in that the lance is normally fixed so that the tip is just level with the metal surface at which point maximum efficiency is claimed. Blowing rates of up to 75000 ft³/h are used and oxygen consumptions are in the range 1300–1500 ft³/ton. One of the reasons for the low oxygen usage is the high proportion of charged ore, almost 2 cwt/ton. Because the bath is long and shallow and the oxygen is blown on to the surface, the slag and metal may be out of equilibrium, but holding the charge for a period under a normal fuel flame can allow the iron in the slag to be reduced to a figure comparable with normal practice.

Russian rotor

The most recently developed oxygen process[9] which combines some of the features of the Oberhausen rotor and the Ajax furnace was commissioned towards the end of 1958. The first unit has only been built to pilot scale, and has a capacity of 15 tons. The system of lancing is similar to the Oberhausen rotor in that it has a primary and secondary jet. The primary jet is immersed in the bath to a depth of $2\frac{3}{4}$–4 in., while the secondary jet is installed some 4–8 in. above the bath surface. As in the Oberhausen process, the secondary oxygen is used for burning the carbon monoxide evolved from the bath. The furnace can be rotated at a speed of 0·2–1·0 rev/min, and it is claimed that this prevents the overheating of the lining, improves thermal efficiency and, by enhancing the mixing within the charge, accelerates the chemical reactions. The oxygen jets are made of copper, the nozzles being convergent/divergent with a 1·1-in. dia. throat. The oxygen pressure at the nozzles is kept constant during the heat at 30 lb/in² for the primary jet and 37 lb/in² for the secondary jet. It is said that the active removal of carbon begins 8–15 min after the start of the blow and also claims that fuming is decreased by increasing the depth of immersion of the primary jet. Oxygen (96–97% purity) is used at a flow rate of about 53000 ft³/h, 22000 ft³/h through the primary nozzle and 31000 ft³/h through the secondary nozzle. The oxygen consumption depends mainly on the carbon content at the end of the blow and ranges from 1340 ft³/ton for carbon contents around 0·8%, up to 1640 ft³/ton for carbon contents below 0·3%. The ferrous oxide content of the slag reduces progressively during a blow from about 45–47% at the beginning of a heat, down to 13–15% towards the end of the blow.

FACTORS AFFECTING MASS TRANSFER

Theoretical considerations

The rate of mass transfer between any two substances can be represented by the equation

$$m = kA\Delta C \qquad \ldots\ldots(1)$$

where m = rate of mass transfer, k = mass transfer coefficient, A = area of contact between substances, and ΔC = concentration difference.

For the total mass transferred, an integration of equation (1) is required. However, the rate equation only need be considered when examining efficiencies which may be defined as

$$\text{efficiency} = m/q \qquad \ldots\ldots(2)$$

where q = oxygen flow rate.

The controlling factors of the oxygen-utilization efficiency are, therefore, the mass transfer coefficient, the interfacial area, and the concentration difference.

Submerged lances or tuyeres

In lancing and bottom-blowing, oxygen (in some cases diluted) is bubbled through the charge and there is direct contact between the oxygen and the metal. Some of the metalloids will react directly with oxygen and of these carbon will give rise to a change in the concentration of oxygen within a bubble. Other reactions, such as that with silicon, give rise to a decrease in the oxygen within the bubble but no change in the oxygen concentration. Owing to the small concentrations of metalloids within the melt, direct oxidation of iron must take place and is probably an important feature of the oxidation reactions. After oxidation the iron will diffuse through the melt until conditions are favourable for a reaction and in the case of carbon, nucleation of CO bubbles. Thus as far as oxygen is concerned the whole of its surroundings can be regarded as a potential 'absorber', even though the actual solubility of oxygen in iron is low. This point has been stressed since most of the work on mass transfer from bubbles to a liquid has been on sparingly soluble systems so that the results are only really analogous to the absorption of gases in an uncombined form.

For sparingly soluble single gas bubbles in a liquid the theoretical mass transfer coefficients are given by either

$$Sh = 2{\cdot}0 + (Sc)^{\frac{1}{3}}\,(Re)^{\frac{1}{2}} \quad \text{(Frössling)}^{10} \qquad (3)$$

or

$$Sh = 1{\cdot}13\,(Sc)^{\frac{1}{2}}\,(Re)^{\frac{1}{2}} \quad \text{(Higbie)}^{11} \qquad (4)$$

where Sh=Sherwood number$=kL/D_m$, Sc=Schmidt number$=\mu_c/\rho_c D_m$, Re=Reynolds' number$=LV\rho_c/\mu_c$, L=a characteristic dimension, D_m=molecular diffusivity of mass, μ_c=viscosity of liquid phase, ρ_c=density of liquid phase, and V=relative velocity of gas bubble to liquid.

Experiments[12] have shown that the Frössling equation only applies for small spherical bubbles, which behave as rigid spheres, and for bubbles which have surface active agents at the interface. The Higbie equation is valid for large bubbles which are not spherical. Calderbank,[13] however, has observed that for clouds of bubbles the only important factors were the liquid diffusivity and whether the bubble was rigid or not.

For small bubbles he found that $k \propto D_m^{\frac{2}{3}}$, and was independent of the bubble size. The absence of any effect of bubble size on k for small bubbles is explicable on the basis of either equation (3) or (4), if the slip velocity is directly proportional to the bubble diameter, a postulate which is substantiated by Allen's data.[14]

On the other hand for large bubbles Calderbank[13] observed that $k \propto D_m^{0{\cdot}86}$, and that bubble size was relatively unimportant over a large range.

It should be noted that the mass transfer coefficient for small bubbles is much less than that for large bubbles.

However, these results only apply for sparingly soluble gases in liquids, and for highly soluble gases (which can be said to be more applicable to oxygen in steel although reaction rather than solution takes place) the mass transfer may depend on the solubility or reactivity of the gas liquid mixture. The physical process of mass transfer as depicted by the Frössling and Higbie equations will, however, be strictly applicable when problems such as nitrogen absorption are being considered.

The second term in the rate of mass transfer equation is the interfacial area which in turn depends on the size and number of bubbles within the bath at any one time. The size of bubbles issuing from orifices has been studied by many workers, but unfortunately their experiments have generally been made on aqueous solutions and at subsonic nozzle velocities. Theoretical studies by Calderbank[15] have shown that for spherical bubbles in a system in which viscous forces are predominant

$$d \propto \left\{\frac{\mu_d^2\,\rho_c}{\rho_d\,(\rho_c - \rho_d)}\right\}^{\frac{1}{3}} \qquad (5)$$

where d=maximum bubble diameter, μ_d=absolute viscosity of dispersed phase, ρ_d=density of dispersed phase, ρ_c=density of continuous phase.

This indicates that the bubble size depends only on the physical system.

Similarly, if surface tension forces are predominant:

$$d \propto \left\{\frac{\sigma}{\rho_c - \rho_d}\right\}^{\frac{1}{2}} \qquad (6)$$

where σ=surface tension. Again the physical properties of the system are controlling.

It has been shown by Liebson[16] that for air and water with high Reynolds' numbers at the nozzle ($\mathrm{Re} > 10^4$)

$$d_{av.} = 0{\cdot}28\ Re^{-0{\cdot}05} \qquad (7)$$

and by Hu and Kintner[17] for liquids falling through liquids and air where surface tension was predominant

$$d_{av.} = \left[1{\cdot}45 \times 10^{-2} \cdot \left\{\frac{\sigma}{\rho_c - \rho_d}\right\}\right]^{\frac{1}{2}} \qquad (8)$$

It can be seen that the experimental formulae do uphold the theoretical analysis, but no account appears to have been taken of the fact that for a gas/liquid interface with a high-surface energy, which is the case for steel, the surface area of the bubbles will be limited by the energy available in the system. Thus, although the above formulae show bubble size to be almost independent of orifice size and flow rate, if the total energy of the new surface formed is taken into account then the energy of the injected oxygen, which depends on pressure and temperature behind the nozzle, is important.

In addition to their size the number of bubbles within the bath at any one time will affect the total interfacial area. The controlling factors in this case will be the depth of penetration, the depth of the bath in bottom-blowing, and the terminal velocity of the bubbles formed. The smaller the bubbles the smaller will be their terminal velocity and at any instant there will be a greater number of bubbles within the liquid so that there will be an increase in interfacial area. There will be a limit to the number of bubbles which are in the bath at any one time. If it is assumed that bubble size, and therefore terminal velocity, is almost independent of flow rate, then as the flow rate increases the number of bubbles increases until they

begin to touch one another. This point is given by

$$nd = V \quad \ldots\ldots(9)$$

where n=number of bubbles/s, d=diameter of bubbles, and V=terminal velocity.

When this occurs there is a direct gaseous path to the atmosphere through which the oxygen can escape. This phenomenon is known as chain bubbling.

The concentration difference term in the rate equation is not a controlling factor if the molten metal is turbulent enough to maintain a uniform composition throughout. However, it would appear that in most processes this may not always be true. For example, in lancing in the OH the stream of oxygen passes through a relatively local volume of the steel and quickly oxidizes this volume. If the turbulence within the bath is very low, as more oxygen is fed into the melt it passes through metal which has already been oxidized and consequently the efficiency decreases. Fortunately the stream of oxygen creates its own turbulence but obviously for optimum efficiency the rate of diffusion of fresh steel into the oxidizing region must be matched with that of the flow of oxygen. Control of the turbulence level within the bath by stirring is therefore desirable.

Surface blowing

In the top-blown processes the general equation for mass transfer rate still holds. In this case the mass transfer coefficient is analogous to the coefficients of heat or momentum transfer. Three of the simpler equations relating mass and momentum transfer are:

$$Sh = f/2.(Re).(Sc) \quad \text{Reynold's analogy}[18] \quad \ldots\ldots(10)$$

$$Sh = \frac{f/2.(Re).(Sc)}{1+5\sqrt{f/2}.[(Sc)-1]} \quad \text{Prandtl's analogy}[19] \quad \ldots\ldots(11)$$

$$Sh = f/2.(Re).(Sc)^{\frac{1}{3}} \quad \text{Colburn's analogy}[20] \quad \ldots\ldots(12)$$

where f=friction factor=function (Re).

Since the Schmidt number, (Sc) is dependent only on the physical properties of the liquid, the mass transfer coefficient for surface blowing is controlled only by the Reynolds' number at the surface.

Bakowski[21] has used a simple model based on molecular collisions to evaluate the mass transfer coefficient as

$$k = \frac{b\,(a+V)}{M^{\frac{1}{2}}P^{\frac{1}{2}}}$$

where a=constant 60, b=constant 1×10^{-6}, V=velocity, M=molecular weight of the gas, and P=total pressure.

It would appear therefore that velocity is the most important physical factor controlling the mass transfer coefficient, although chemical reaction rates may again be important.

The area exposed to the top- or surface-blown jet will depend on the aerodynamics of the process. For example, replacing one jet by two jets suitably disposed, or increasing the momentum of the jet to give a deeper depression, will increase the exposed area.

As with immersed injection, the concentration difference is controlled by the turbulence of the bath. With top-blowing the oxygen contents of the surface will tend to build up so that the slag and metal will be away from equilibrium, unless stirring by the jets or by the carbon boil can create enough turbulence.

Oxidation of droplets

When top-blowing, large quantities of material are torn from the surface and are oxidized in the oxygen atmosphere above the bath. The controlling factors are the same as those for bubbles in a liquid, but as the Reynolds' number of the particles will generally be lower than that of the oxygen over the bath surface the mass transfer coefficient will not be as great as the direct oxidation of the bath, assuming that the composition of both is the same.

Whether the droplets play an important part in the oxygen transfer depends on their area. Because of the relatively low mass transfer coefficient it is probable that the surface area of the droplets would have to be of the order of 50 ft^2 (about ten times the area exposed by the jet) so that with droplets of 0·12 in. dia., then about 40 lb of steel must be in the atmosphere above the bath. For a 50-ton LD vessel with a volume above the charge of about 1500 ft^3 this would represent an average concentration of 70 droplets/ft^3 with an average distance between droplets of 3 in. If such a state of affairs exists, the droplets will be playing an important part in the oxygen transfer process. It might be argued that the size of droplet considered above is excessively large and that by reducing the size the same area could be obtained for a lower mass loading. However, if the droplets are too fine they will not fall back into the bath, and there will be a loss in oxygen efficiency and metallic yield.

For the size of droplets which are formed, internal circulation will be low[22] so that once the surface has been oxidized the concentration difference between the droplet and the atmosphere will remain at a low level and the rate of mass transfer lowered. If therefore the turbulence within the bath is maintained at such a level that fresh unoxidized metal is constantly being exposed to the oxygen then the bath is by far the greater potential absorber.

ENERGY AVAILABLE FOR STIRRING

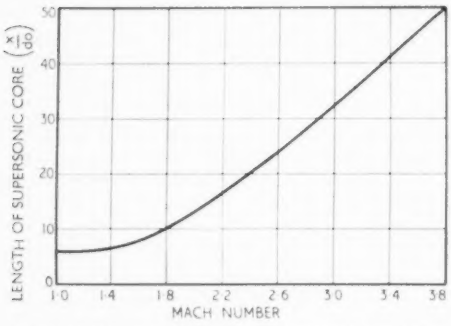
Energy is available in all the oxygen processes in two forms: mechanical and thermal. The thermal energy released owing to exothermic reactions is of the order of 10^6 BTU/ton, whereas the mechanical energy available may only be of the order of 10^3 BTU/ton. Consequently although experience has shown that within experimental error the exothermics account for the rise in temperature of the bath and heat losses, no estimate can be made of the total mechanical energy in the bath, since only 0·1% conversion of thermal to mechanical energy could double the mechanical energy available.

Assuming an oxygen consumption of 1200 ft^3/ton and all the energy in the oxygen stream given to the bath, the following mechanical energies are available.

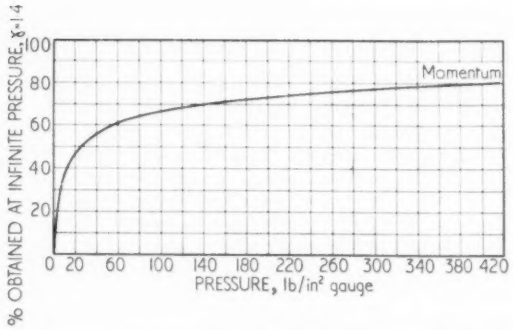
Energy of oxygen stream (assuming adiabatic expansion)

Pressure, lb/in^2 (average)	Energy, BTU/ton
45	$3{\cdot}1\times10^3$
90	$4{\cdot}6\times10^3$
135	$5{\cdot}4\times10^3$

In the information available on the 30-ton Kaldo vessel it has been stated[23] that the energy supplied to rotate the vessel at 30 rev/min is $0{\cdot}5\times10^4$ BTU/ton



2 *Effect of discharge velocity on supersonic core (after Anderson)*



3 *Variation in momentum produced on expansion from various pressures*

(1·5 kWh/ton).* This includes all friction losses so that the actual mechanical energy supplied to the charge will be less. Obviously in the Oberhausen and Soviet rotors which rotate at a maximum of 1 rev/min the mechanical energy supplied from the rotation of the vessel will be much less than in the Kaldo.

It can be seen therefore that the energy available from an external jet is of the same order as that supplied by rotating the vessel. It must also be remembered that whereas rotation gives all the energy to large-scale movements within the bath, a jet may have a much more localized action. In addition, some of its energy is used in tearing droplets from the surface, but this is probably small compared with the total available.

SIMILARITY FOR MODEL EXPERIMENTS

It is difficult to make measurements on full-scale oxygen steelmaking plant because of the high temperatures and vigorous chemical reactions. It is desirable therefore that some attempt be made to model the processes and hence an examination of the similarity criteria is necessary.

Unfortunately the necessary conditions for complete similarity are impossible to achieve since there are five regimes to be satisfied at the same time. These are: steel, slag, steel and slag particles in the atmosphere above the bath, oxygen 'jet' whether it be top-blown or immersed, and gases above and in the molten metal evolved from the carbon–oxygen reactions. It can be shown, using Buckingham's theorem, that such a system can be completely defined by 24 dimensionless groups. Admittedly six of these are geometrical groups and some of the remaining 18 could possibly be eliminated, but even so the solution of such a similarity problem is impossible. It is therefore necessary to approach the modelling of the oxygen steelmaking processes with the knowledge that it is impossible to achieve similarity and though the results from laboratory scale models may be both interesting and useful the only scaling factor available is personal intuition.

For example, the problem of similarity criteria for movement of the steel and slag droplets in the atmosphere above the bath has been examined by Granville[24] who showed that Reynolds' number, Froude number, and a particle number must be satisfied. The particle number was defined as

$$P = UV/gL$$

where U = free falling speed of particle, V = a characteristic velocity of the system, g = acceleration due to gravity, and L = a characteristic dimension.

In addition, the particles must be admitted to the system at similar locations, with similar velocities, and in similar directions. It is the latter criteria which immediately raise a problem. There are two possible sources of particles in the atmosphere above the bath disruption of the surface by carbon monoxide bubbles, and the physical action of the jet on the bath. The final direction of the particles arising from both mechanisms will be affected by the movement of the steel and the slag. Also the effect on the carbon monoxide bubbles of buoyancy, viscous drag, and surface tension must be allowed for since these will also affect the size, velocity, and direction of the particles. Even if a liquid–gas system can be found to give the correct hydrodynamics it is doubtful if the particles would be of the right size to give the correct particle number. Consequently exact similarity seems impossible.

Similar examinations of the mass transfer and the hydrodynamic problems also show that the results obtained may not be altogether similar to those at full scale. However, if this is borne in mind, laboratory-scale experiments can be useful in that trends on one scale may indicate the trends on a larger scale.

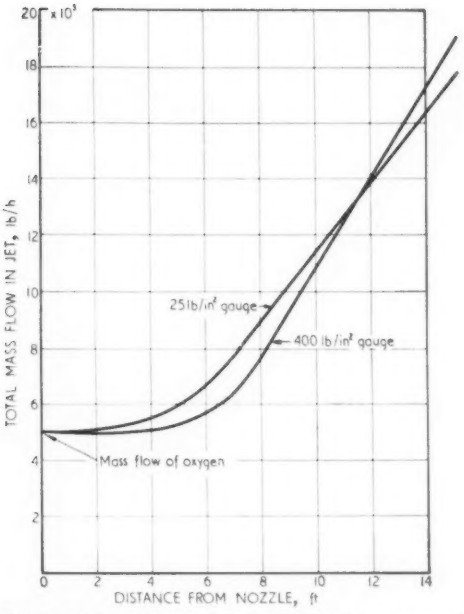
THE OXYGEN JET

Entrainment of gases and particles

If the lance is held some distance above the surface of the bath then the oxygen jet will entrain some of the furnace atmosphere thus lowering the oxygen concentration. It may be desirable in some processes to withdraw the lance as far as possible to avoid mechanical problems and therefore some knowledge of what effect this may have on oxygen concentration at the surface is essential.

When a gas is discharged through a nozzle into the atmosphere a so-called 'free jet' is produced. Immediately downstream of the nozzle there is a region, the potential or supersonic core, where the jet spreads relatively slowly and little entrainment of the surrounding fluid takes place. At discharge velocities up to the speed of sound this core is some 4–8 dia. long

* Recent information suggests that a figure of $1{\cdot}0\times10^6$ to $1{\cdot}3\times10^6$ BTU/ton (3 to 4 kWh/ton) will be required on the larger Kaldo vessels.



4 *Effect of distance from nozzle on vitiation of an oxygen jet at 25 and 400 lb/in² average*

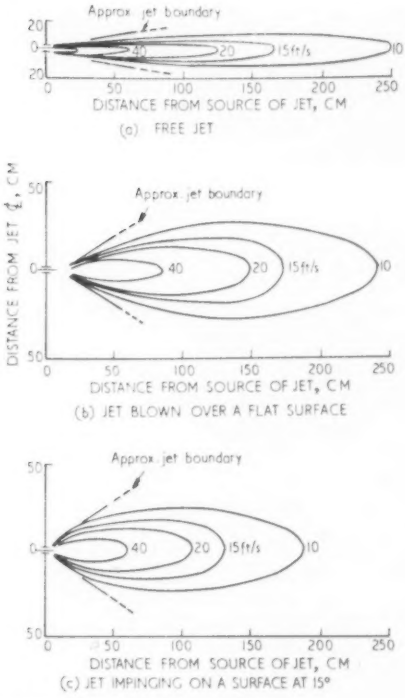
while at supersonic velocities it increases almost proportionally with velocity[25] as shown in Fig.2. This transition zone is followed by full development of the free jet which expands at a total angle of about 20° due to mixing with the surrounding fluid, the rate of mixing or entrainment following the relationship:

$$M = Kx\sqrt{G}$$

where M is the total mass flow in the jet, G is the jet momentum, x is the distance from the origin of the jet, and K is a constant.

It can be seen that at a given distance from the origin of the jet the mass entrained depends only on the momentum, so that for a given mass flow of oxygen the mass entrained depends only on the velocity of the oxygen after expansion through the nozzle. Thermodynamically there is a limit to the velocity which can be obtained, and consequently the momentum obtainable has an upper limit. The momentum produced when oxygen expands through a nozzle from various pressures is shown in Fig.3. Above 140 lb/in² gauge there are only relatively small gains in momentum to be obtained.

However, the velocity of the oxygen as it leaves the nozzle also determines the length of the supersonic core so that over the initial portions of the oxygen jet the mass of vitiating gases and particles entrained is lower for the higher momentum jets. For example for an oxygen flow of 1000 ft³/min at a pressure of 400 lb/in² gauge a Mach number of greater than 3 can be achieved resulting in a core of over 3 ft long, whereas at 25 lb/in² gauge the core has a length of about 1 ft. The two entrainment curves will be as shown in Fig.4. These show that the effect of entrainment on the oxygen concentration is negligible, below 2 ft for both jets, but if it is necessary to withdraw the lance tip from the bath surface to any distance between 2 and 12 ft then the higher momentum jet is less



5 *Interaction of a jet with a surface*

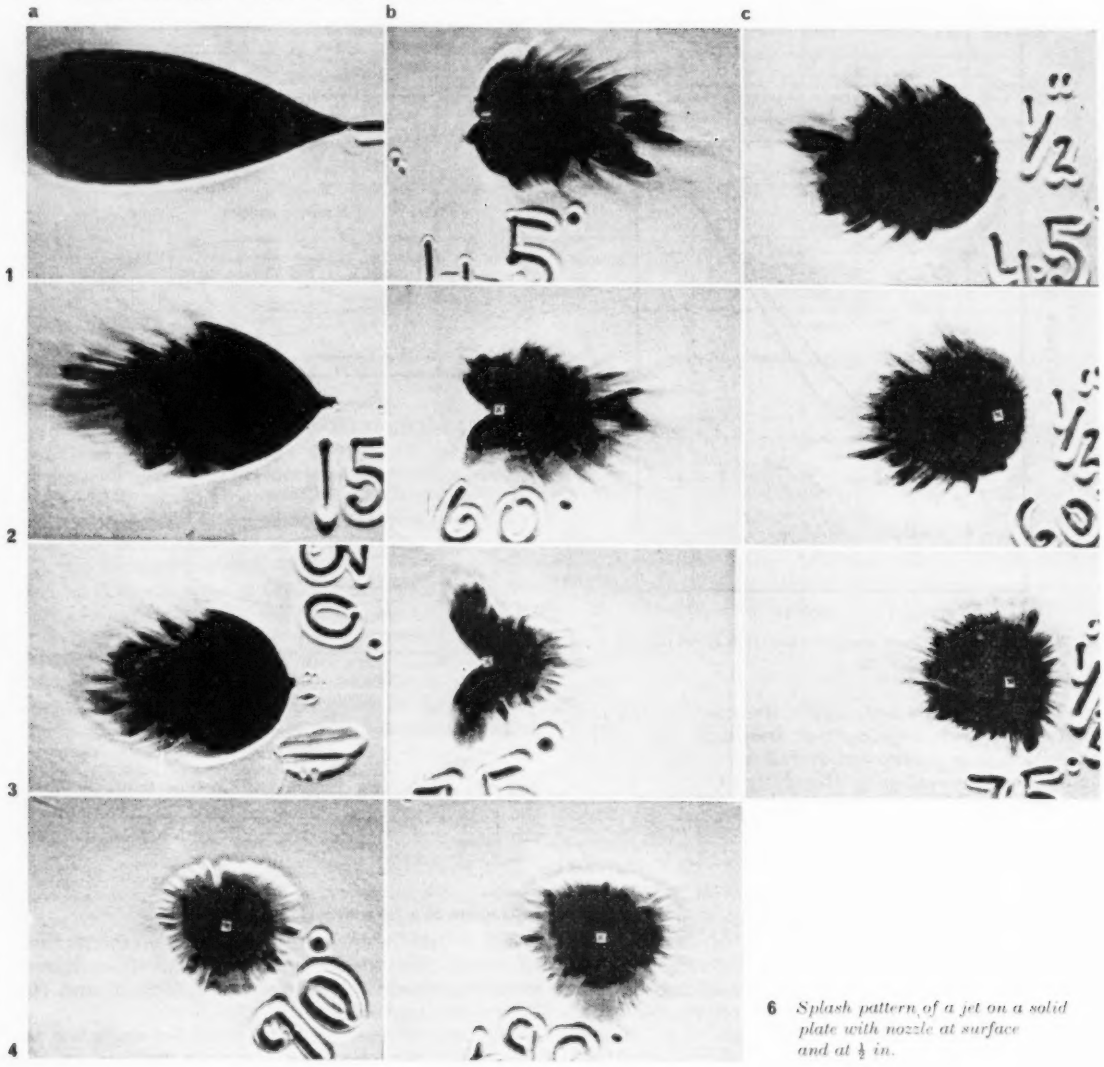
vitiated. Thus, at a distance of 5 ft 6 in. from the bath, the average oxygen concentrations on impingement are 90% and 80% for the high- and low-momentum jets respectively.

Interaction of a jet with a plane

When a jet impinges on a plane the interaction, whether it be in the form of mass, momentum, or heat transfer, depends on the area of contact and the Reynolds' number.

The area of contact depends on the angle the jet makes with the plane, since when it impinges on the surface its profile is distorted. Figure 5 shows that even when a jet is blown parallel to the surface there is a marked increase in its rate of divergence (50° total angle; cf. 20° for the free jet). Inclining the jet at an angle of 15° to the surface causes the velocity contours to broaden still further, and further steepening increases the spread, until with a vertical jet the contours are a series of circles around the jet axis. Figure 6 shows photographs of various splash patterns obtained by blowing a jet of air on to a sheet of black perspex covered with polystyrene particles. It can be seen that the area swept clean is greater at the lower angles of inclination, but this does not necessarily mean that the mass transfer will be greatest since the mass transfer coefficient, a function of Reynolds' number, must also be considered.

If the mass transfer coefficient is high, so is the momentum transfer coefficient and consequently the drag on the surface will be high. Figure 7 shows the axial decay of velocity for an air jet impinging at different angles on a solid surface. The fact that the decay of dynamic head at 0° is less than 15° indicates



a1	0°	h=0	b1	45°	h=0	c1	45°	h=½ in.
a2	15°	h=0	b2	60	h=0	c2	60°	h=½ in.
a3	30°	h=0	b3	75°	h=0	c3	75°	h=½ in.
			a4	90°	h=0	b4	90°	h=½ in.

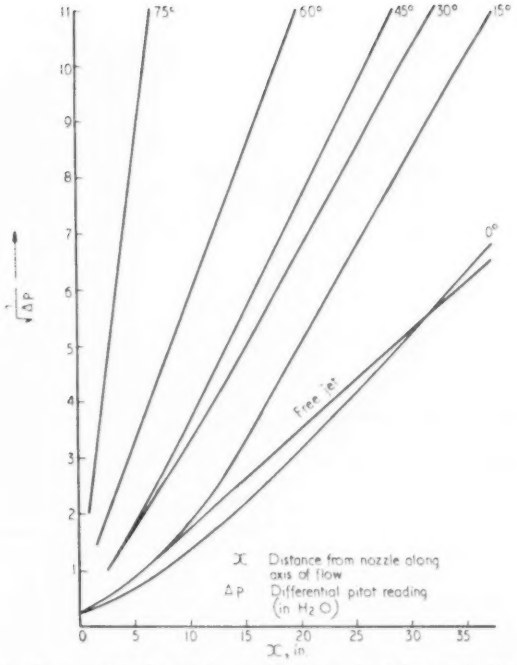
6 *Splash pattern of a jet on a solid plate with nozzle at surface and at ½ in.*

that the drag forces are less. It can be seen that between 30° and 45° the velocity decay is insensitive to angle changes, but beyond 45° large changes in dynamic head occur. This fact may be explained from Fig.6 which shows that beyond 60° backward flow occurs.

Measurements were also made of the momentum of the gas stream after it has passed over the surface by means of an impact plate. The results obtained at angles up to 45° are shown in Fig.8, along with the results of Fage and Johansson,[26] who determined the drag coefficients for a flat plate inclined at various angles to the stream. The loss in momentum increases rapidly at low angles of inclination. Further measurements showed that for a solid plate the slant distance of the jet from the surface had very little effect on the loss of momentum.

The loss of momentum when a jet strikes a liquid, rather than a solid, surface has also been measured by the impact plate method. It was shown that the slant distance of the nozzle from the surface was very important. When the nozzle was at the liquid surface all its momentum was destroyed, but as the nozzle was withdrawn the momentum loss decreased as shown in Fig.9. Another interesting feature was the effect of angle of inclination. At low angles, as the lance was withdrawn, the loss in momentum approached that obtained with a solid plate, whereas at steeper angles this was never reached. Thus the total drag on the liquid surface was in general greater than that on a solid surface but in the case of a liquid the distance from the surface was important.

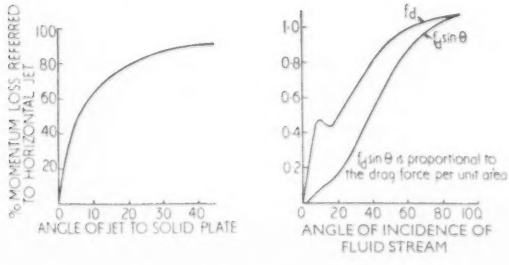
The situation is therefore rather complicated since it is the product of area and mass or momentum transfer coefficient which controls rate of mass transfer. Low lance angles give large areas of contact but low transfer coefficients, whereas high lance angles



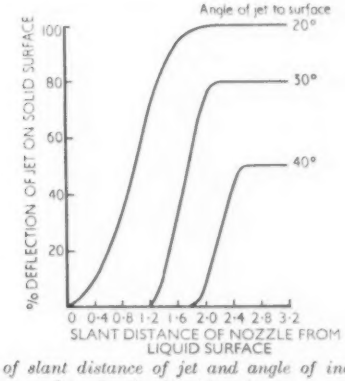
7 *Comparison of axial decay of dynamic head for jets inclined to a plane* (After Fage and Johansson)

give small areas but high transfer coefficients. One might therefore be tempted to state that there is an optimum angle, but this is difficult to justify. For example, taking the areas shown in Fig.6 and the drag data given in Fig.8, the resulting product shows a maximum between 50° and 60° (Fig.10). However, in practice the presence of a slag layer further complicates the issue since the splash pattern the jet makes on the slag will not be as important as the contact area between steel and oxygen. The area of steel exposed will depend, among other factors, upon the momentum of the jet and the physical properties of the slag so that the determination of the optimum angle, if one exists, can only be made on the steelmaking plant.

The process of oxygen transfer is further complicated by the fact that CO is liberated from the bath. This will reduce the drag because it effectively increases the thickness of the boundary layer. Experiments in which air was passed through a holed plate showed that the loss in momentum was much more at shallow, than at steep, lance angles.


% MOMENTUM LOSS REFERRED TO HORIZONTAL JET
ANGLE OF JET TO SOLID PLATE
f_d
$f_d \sin\theta$
$f_d \sin\theta$ is proportional to the drag force per unit area
ANGLE OF INCIDENCE OF FLUID STREAM

8 *Effect of jet inclination on the drag on a solid plate*



9 *Effect of slant distance of jet and angle of inclination on momentum of gas leaving liquid surface*

MODEL EXPERIMENTS

Where an oxygen jet impinges on a bath of molten iron the extreme conditions preclude detailed observations. Although it has been stated earlier that it is impossible to model the system exactly, it is considered that certain small-scale experiments can be a useful means of indicating trends which are likely to occur at full scale. In the experiments described below no attempt has been made to simulate chemical reactions, which may have a profound effect on the physics of the process. Also, the difference in bubble size and buoyancy forces between models and the full scale plant will modify some of the phenomena observed.

Top-blowing

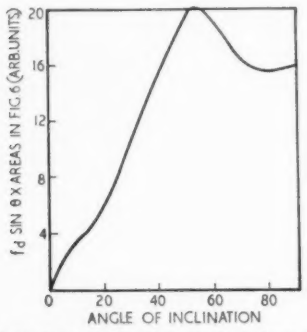
Factors affecting the shape of the surface disturbance

When a gas jet impinges on the surface of a liquid a crater is formed with what might be termed a 'bow wave' on the 'trailing edge' of the depression. The shape and size of these characteristic features depend on: (i) the flow rate of the gas, (ii) the nozzle diameter of the jet, (iii) the distance of the nozzle from the liquid surface (iv) the angle of inclination to the liquid surface of the jet, (v) the physical properties of both the liquid and the gas.

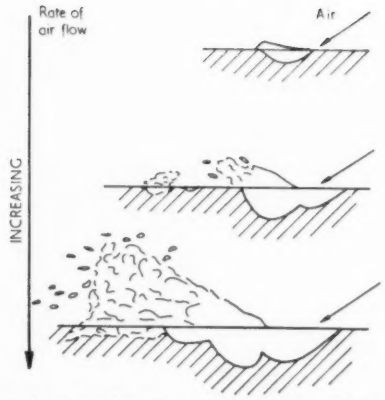
It can be shown that the weight of liquid displaced must lie somewhere between one and two times the component of the jet momentum perpendicular to the liquid surface, but the prediction of the shape of the depression is not quite so obvious. The slopes of the crater walls will be a controlling factor on the dimensions of the depression, while these in turn will be controlled by the drag force of the gases flowing over the liquid surface, the specific weight of the liquid, and its viscosity.

However, despite the complexity of the problem it can be stated that: (i) increasing the flow increases the depth, length, and volume of the crater (Fig.11), (ii) decreasing the nozzle diameter will have similar effects, (iii) increasing the distance of the jet from the surface increases the length and breadth, but gives a shallower crater, (iv) as the jet is inclined more steeply the depth increases, the length decreases, and there is little change in the width.

The effect of changing the physical properties of the liquid is difficult to evaluate since density, surface tension, and viscosity may all be important. However, simple small-scale experiments using water, oil, and glycerine for which the viscosities are markedly



10 *Effect of angle of inclination on drag force for the region where the jet hits the solid surface*



11 *Change in depression shape with increasing air flow*

different, have shown that with the more viscous fluids less volume is displaced and the length of the crater is shortened (Fig.12).

Collins and Lubanska[27] have reported data correlating the depth of depression with the momentum, the angle of inclination of the jet, and its distance from the surface for air jets on water, and from this have forecast the depression depth which would be made in a bath of steel. It would, however, seem dangerous to prophesy what the effect of changes in liquid properties would produce.

If the surface is examined more closely by means of a stroboscope it is found that surface waves are generated within the crater which have a definite amplitude and frequency for a given set of physical conditions. These surface waves are propagated across the whole surface of the liquid, gradually decaying because of the viscous forces. Where these waves leave the crater they experience an abrupt change in direction and create the so-called 'bow wave'. As the flow rate of gas increases so does the frequency of the surface waves until at a certain point they tend to break up, thus giving rise to 'spitting' from the crater edge (Fig.11). Surprisingly little is known about the formation of surface waves although a recent review by Charnock[28] suggests that when the relative velocity between air and liquid reaches a critical value then waves will be formed. He also states that viscosity (Fig.12) and surface tension both have a stabilizing influence. Data are given in which the critical friction velocity is found to be proportional to the fourth root of the absolute viscosity. This may explain why it has been observed in practice that the particles in the furnace atmosphere are mainly iron, not slag, since the viscosity of slag is very much greater than that of iron.

Flow pattern within a single liquid

The flow patterns in a small tank, 12 in. × 6 in. × 6 in. have been examined for different liquids under varying conditions. It has been found that there is a basic flow pattern within a single liquid, which is as shown in Fig.13. Increasing the flow rate or decreasing the nozzle size increases the energy of the gas stream and enhances the stirring within the liquid but does not change the pattern. However, for a given container above a certain gas flow rate, the liquid tends to slop. A possible explanation of this is that at the higher gas flow rates the waves generated within the crater do not decay before reaching the walls of the vessel where they are reflected. Interference with the waves coming from the crater gives rise to greater wave amplitudes and instability of the liquid surface. Obviously, with such a phenomenon, viscosity and the distance of the crater from the walls are important.

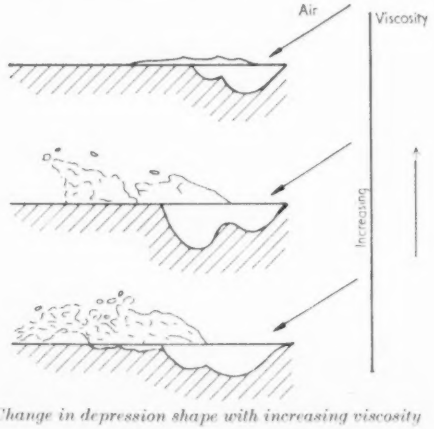
The effect of jet inclination to the bath on the flow pattern is not very marked. For low angles of impingement the surface flow pattern gives rise to recirculation currents along the length of the bath with weaker currents across the width of the bath. As the jet is inclined more steeply the transverse flow tends to strengthen at the expense of the longitudinal flow.

The distance of the jet from the bath has more effect on the depression than the flow pattern, although there is a tendency for the surface pattern to be more pronounced as the jet is withdrawn.

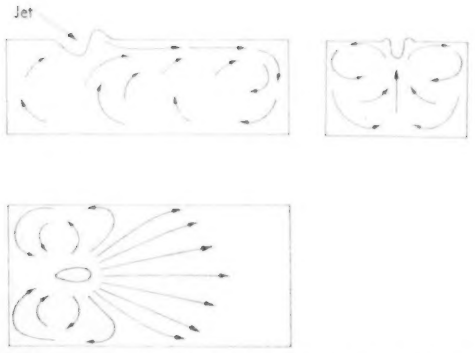
Other factors examined were viscosity and the dimensions of the container. Increasing the viscosity gives rise to a less pronounced movement of the liquid, although the flow pattern is unchanged. If either the bath length or width is increased, then for a given gas flow rate the movement within the body of the liquid is decreased, the surface velocities decaying before they reach the walls to such a low level that they cannot promote recirculation. If the bath is made more shallow then liquid movement below the crater becomes more pronounced.

Flow pattern with a two-liquid system

The flow patterns obtained for air jetting on to a layer



12 *Change in depression shape with increasing viscosity*



13 *Flow pattern in a single liquid when a gaseous jet strikes the surface*

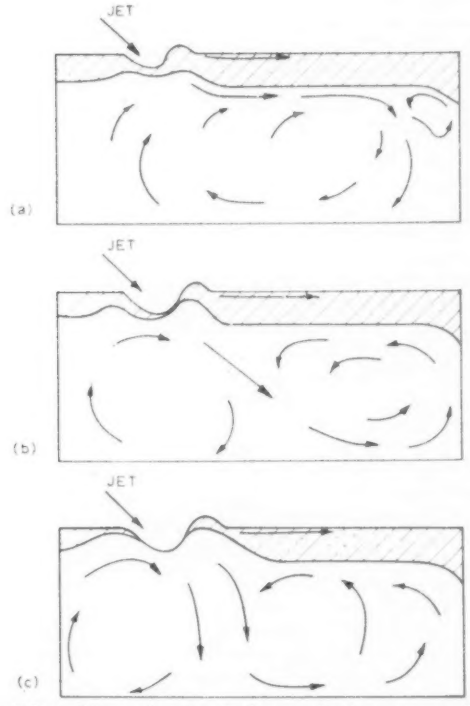
of oil on water, for three rates of flow, are shown in Figs.14*a–c*. Figure 14*a* shows the system when the flow is low and the layer of oil is not penetrated. Near to the crater the oil layer is much thinner than elsewhere, while at the far end the thickness of the oil layer increases. The flow pattern within the water is very similar to that obtained with a single liquid except for a small zone of recirculation at the end of the bath where the oil layer is thicker. This similarity in flow pattern must be because the effect of surface drag forces extends through the oil into the water. It was observed that at extremely low gas flows the water moved in the opposite direction, presumably owing to drag from the recirculation currents in the oil, but these flows were so small that the movement caused in the liquid was hardly perceptible. The flow pattern within the oil could not be observed because, immediately the air jet was switched on, the oil became saturated with air bubbles making it opaque.

At a flow rate such that the oil was just penetrated, a markedly different flow pattern was observed (Fig.14*b*). In this case the flow just below the oil layer beyond the crater was in the reverse direction to that at lower air flows. It would seem that the bow wave in the water is held down by the oil, thus causing the water stream to be deflected downwards.

At higher flow rates (Fig.14*c*) the thickness of oil behind the crater decreases still further and the water streams away from it at a steeper angle.

Effect of a 'carbon monoxide' boil

To examine what possible effects a carbon monoxide boil might have on flow pattern, the bottom of the small tank was fitted with a felt base so that the liquid could be aerated to give a physical simulation of carbon monoxide bubbles. The flow was restricted so that foaming did not occur. It was found that the aeration of the water had no pronounced effect on either the shape or size of the depression created by an impinging air jet, or on the flow pattern within the liquid as far as could be seen by eye. It was, however, plainly seen that when the jet was switched on, the originally vertical paths of the bubbles were deflected by the flow pattern caused by the jet, so that more bubbles broke through the surface nearer the crater. It must be remembered, however, that the physical simulation used could not take into account the effect of nucleation centres, or the effect of bubble size, both of which will be extremely important in practice.



14 *Effect of increasing the air flow on the flow pattern within a two-liquid system*

Submerged lances

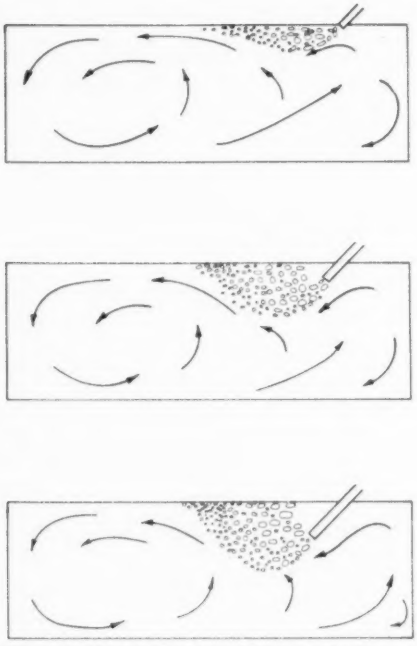
Bubble trajectories

The paths of the bubbles formed when a submerged lance is used to introduce a gas into a liquid could be determined if the drag coefficients were known, but in regions near to the lance these cannot be obtained from present data. However, if the effect of drag is ignored, it can be shown that the depth a bubble can penetrate into a liquid is proportional to the square of the component of velocity perpendicular to the surface.

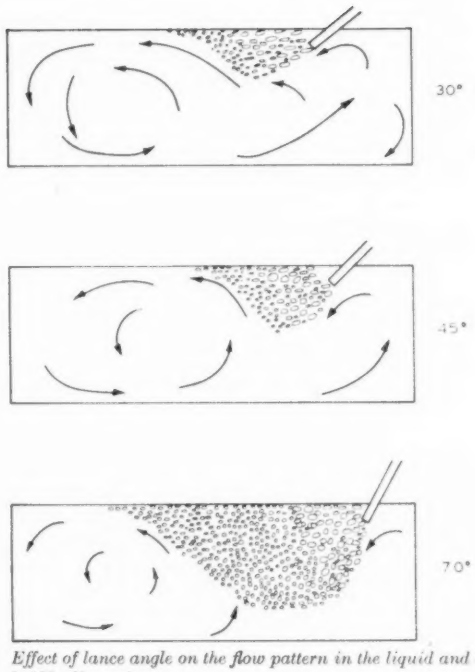
The time a bubble stays within the liquid depends only on the vertical velocity component of the bubble, but the dispersion of the bubbles throughout the liquid depends also on the horizontal component. Bubble size is important in that the terminal velocity of small rigid bubbles is much less than that of large unstable bubbles. Consequently small bubbles have a greater residence time within a liquid than large bubbles, and have a more elongated trajectory so that they pass through a greater volume of liquid. It is possible that the terminal velocity could be so low that the flow pattern within the liquid exerts drag forces that are stronger than the buoyancy forces, thus giving a dispersion throughout the liquid which is determined by the flow pattern.

Depth of immersion

Figure 15 shows the flow pattern and bubble trajectories for air injected into water for three different positions of the lance at the same flow rate. It can be seen that the depth of penetration of the gas into the liquid below the lance tip is about the same in all cases, and there is no marked change in flow pattern.



15 *Effect of depth of immersion of lance on the flow pattern in the liquid and the bubble dispersion*



16 *Effect of lance angle on the flow pattern in the liquid and the bubble dispersion*

However, more dispersion of the bubbles occurs at the greater depths of immersion.

Lance angle
The results obtained at three lance angles are shown in Fig.16. The dominant flow tends to be pushed away from the lance as the angle is steepened. Increasing the inclination also gave most dispersion, and hence the greater interfacial area. It should be noted, however, that this marked change in dispersion is due solely to the small bubbles.

Rate of flow
As the flow is increased, the effects observed are very similar to those obtained with increases in lance angle.

Effect of 'carbon monoxide' boil
Air bubbles were introduced into the liquid to simulate a carbon boil, but no change in dispersion or flow pattern was observed.

REFRACTORY WEAR

No discussion on any steelmaking plant would be complete without some mention of the factors affecting refractory wear. This has received less attention in the new oxygen processes than in the modified processes such as the oxygen-lanced open-hearth. The importance of refractory wear is, however, obvious since it often determines the limiting blowing rate.

Exact simulation of the formation and deposition of iron oxide and slag particles by means of a model is impossible. However, the results of a few *ad hoc* experiments may be worthy of reporting if only to underline the difficulties involved.

When air was blown on to water in a model of an OH furnace it was found that the deposit on the roof was greatest at shallow lance angles. It may be however, that the bursting of the carbon monoxide bubbles at the bath surface provides an important contribution to the total number of droplets in the furnace atmosphere. In an attempt to simulate this, experiments were made with an aerated bath, and it was found that no simple statement could be made as to the effect of lance angle. For certain lance positions and flow rates, the maximum deposition rate occurred at an inclination of about 45°, but under other conditions this angle coincided with minimum deposition rate. Moreover, it was found that under certain circumstances neither the air jet nor the aeration alone gave any measurable deposit on the roof, but at the same flow rates a combination of the two gave a large deposit.

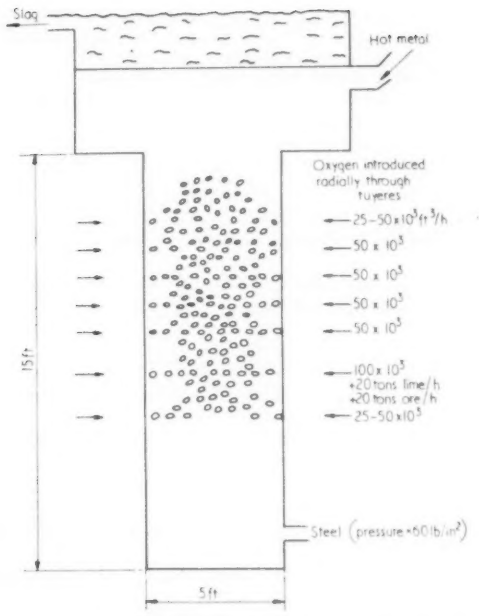
Even though it is impossible to draw any conclusions from this model work, two ways of reducing deposition suggest themselves, i.e. to spread the carbon monoxide evolution more evenly over the bath and to reduce the drag of the jet on the surface. With top-blowing, multi-hole lances immediately suggest themselves as a means of satisfying these criteria.

CONCLUSIONS

In this paper an attempt has been made to analyse the process of mass transfer in oxygen steelmaking. Since it is virtually impossible to obtain much of the data from full-scale plant, theoretical and model studies have been made to try to explain some of the practical observations. It has already been shown how the efficiency of oxygen usage depends upon three factors: k, the mass transfer coefficient, R, the interfacial area, and ΔC, the difference in concentration. For all the oxygen to be absorbed there is a minimum permissible value of kA which occurs when the surface concentration of oxygen is at a maximum. Thus:

kA must be $> q/\Delta C$

where q=oxygen flow rate.



Reaction volume: 230 ft³ (*cf.* 250 ft³ for a 50-ton Bessemer)
Output rate: 300 ton/h

17 *Schematic diagram of proposed continuous refining tower*

For a flow rate of 1000 ft³/min, this means that kA must be at least 16·7 ft³/s, which can be used as a design criterion. Unfortunately k cannot readily be determined because of the lack of physical data, and with submerged lances the interfacial area is not known. However, despite this, values of the mass transfer coefficient have been calculated assuming molecular diffusivities of 1×10^{-5} cm²/s for steel and 1×10^{-7} cm²/s for slag as follows:

	Mass transfer coefficient (k) (ft/s)	
	Steel	Slag
Large bubbles	30×10^{-3}	1×10^{-3}
Small bubbles	10×10^{-3}	$0{\cdot}5\times10^{-3}$
Vertical jet on plane	$10\,v\times10^{-3}$	$0{\cdot}01\,v\times10^{-3}$

where v is the velocity of the liquid at the surface.

It can be seen that the mass transfer coefficients are very much greater for steel than for slag, which explains the practical observation that it is necessary to penetrate the slag and provide contact between steel and gaseous oxygen.

For submerged lances, bubble size is important, not only because of the difference in the mass transfer coefficient between large and small bubbles, but also because of the difference in interfacial area. It can be shown that as the flow rate is increased kA rapidly approaches a maximum beyond which it assumes an almost constant value. Providing ΔC remained unchanged, the efficiency of oxygen transfer would be maintained at a constant value no matter by how much the flow rate was further increased. However, the local metal will sooner or later become saturated with FeO and the efficiency will decrease. The point at which saturation occurs will depend on the degree of mixing which is likely to be different for different shaped vessels. This, then, would explain the fact that with a single lance there appears to be an optimum blowing rate and that this optimum occurs at a different point in different shapes of furnace. For a kA of 16·7 it can be shown that the amount of oxygen which would have to be held in the bath at any one time would be less than 1 ft³. At a flow rate of 16·7 ft³/s, this should be easy to obtain without too great a depth of immersion.

With surface blowing for a given lance size at low flow rates, very little metal will be exposed. As the pressure, and hence flow, is increased, the area of metal exposed per unit of mass flow increases rapidly. However the surface area of the depression (slag+steel) does not increase *pro rata* with the flow rate because the nozzle velocity approaches a maximum value (Fig.3). Consequently, beyond a certain pressure the increase in surface area due to the deepening of the depression will not be as great as the increase in mass flow rate, i.e. the area of metal exposed per unit of mass flow will decrease. It could, therefore, be concluded that there will be an optimum blowing pressure for a given lance size which will depend upon the thickness and properties of the slag. If the area of metal exposed is 5 ft² then to achieve a kA of 16·7 would require a surface velocity of the melt of over 300 ft/s, which illustrates the importance of producing as high a jet velocity as possible. It would appear again, that a kA of 16·7 ft³/s is possible.

The practical values of kA attainable indicate that the main barrier to oxygen transfer is in the ΔC term. This might be, in the gaseous phase, due to the thickness of the boundary layer, but this is unlikely at the injection velocities normally used, although the boundary layer might effectively be thickened by the evolution of CO. More probably the main barrier to mass transfer is in the metal, in which case stirring the bath would improve matters, or alternatively the oxygen could be injected more uniformly through the melt. From this point of view the Bessemer process would appear to be sound.

In all other processes, except the Kaldo, the energy required for stirring the metal is supplied from the oxygen jet itself. It is essential therefore to work at as high a pressure behind the lance as is practicable. This will bring refractory wear problems due to splashing, but suitable disposition of multiple jets or lances could alleviate this. As there is an upper limit to the energy which can be supplied by a given mass flow, mechanical agitation as in the Kaldo process would appear to warrant more thorough investigation.

Little has been said as to what is an ideal shape of vessel, but if stirring is important, then the metal/refractory interface should be a minimum to reduce frictional losses. The 'pear-shape' of the LD or Bessemer vessel would appear to be satisfactory from this point of view, whereas the shallow OH would not.

No matter what the process, the product of the mass transfer coefficient and interfacial area should be at least equal to the flow rate of oxygen. That is to say the rate of supply of reactants (O_2 and Fe) should be matched. This criterion could be achieved either by adequate stirring of the melt or by suitable design.

In the past, chemical engineers have always, where possible, used counterflow processes for simplicity and high efficiency. Looking into the future, we may some day see steelmakers using similar techniques and

pouring molten metal down a column while bubbling oxygen through it. Further, there is no reason why slagmaking constituents should not be injected in with the oxygen and, if necessary, the temperature of the final mixture could be controlled by ore additions. A tentative suggestion of what such a vessel might look like is shown in Fig.17. It should, theoretically, be capable of conversion rates of 5 tons/min which, at an availability of 86%, would represent a steel production of $2\frac{1}{4}$ m. tons per annum.

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STAL *in English*

No. 7 of the 1960 series of *Stal in English* has been published and subsequent issues will appear at about monthly intervals. Principle contents of nos. 7 and 8 are given below. Full details of subscriptions to *Stal in English* are available from the Secretary of The Iron and Steel Institute.

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No.8

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The quality of oxygen-blown rimming converter steel

Mechanical and thermo-mechanical strengthening of low-alloy and low-carbon steels

ECONOMICS AND ORGANIZATION

The useful life of steel

Discussion at the joint meeting on corrosion

A joint meeting on corrosion was held in the Hoare Memorial Hall, Church House, Westminster, London SW1, on Thursday, 15 October 1959. The Chair was taken at Session I by Dr U. R. Evans, F.R.S., for The Iron and Steel Institute, and at Sessions II and III by Mr L. Kenworthy, for the Society of Chemical Industry.

Session I Discussion on atmospheric corrosion of bare metals

The **Chairman** (Dr U. R. Evans) introduced Dr **J. C. Hudson** (BISRA): This session deals with atmospheric corrosion, and I will refer briefly to some of the salient features of the Committee's work in this field.

Several series of long-period corrosion tests have been carried out. For example, Fig. 20 (p.64) of the Report shows the results of five series of tests, some of which lasted for 15 years, on ordinary mild steel exposed at Sheffield. Although the first series was exposed in 1933 and the fifth in 1941, the results are very reproducible. The curves are parallel and approximate to straight lines, although detailed examination shows that the rate of rusting was greater during the first year or so than later on. The average rate of corrosion over 15 years was 0·004 in. per year. This may be regarded as a representative figure for industrial atmospheres in the UK.

Many comparisons of the corrosion resistance of the ordinary structural irons and steels have been made. A general picture of the results is given in Fig.*A*. The purest material of all, a Swedish wrought iron made with charcoal, also proved to be the most corrodible, thus refuting the old theory that the purer the iron, the greater would be its corrosion resistance. Otherwise the materials fall into three broad groups. The first and most corrodible includes the unalloyed low-carbon steels. The second group contains UK wrought irons, copper-bearing steels, and copper-bearing Swedish wrought iron. The third and most resistant group consists of low-alloy steels alloyed with small percentages of copper and chromium. Although it was not included in the tests, the well-known proprietary steel Cor–Ten would rank among the best steels in this group.

Some thought has been paid to the reasons for the improvements in corrosion resistance brought about by the addition of small amounts of copper and other alloying elements. As shown in Fig.21 (p.65), the results support the theory advanced by the American investigator H. R. Copson, that the better resistance of low-alloy steels is associated with the accumulation of basic sulphates in the rust formed on them. Both in the British and the American tests, the corrosion resistance of the steels increased with the sulphate content of their rusts. The properties of the rust are of great importance, both in determining the resistance of bare steel and also the ease and efficiency of protective painting. For this reason a fundamental investigation of the subject has been begun by BISRA.

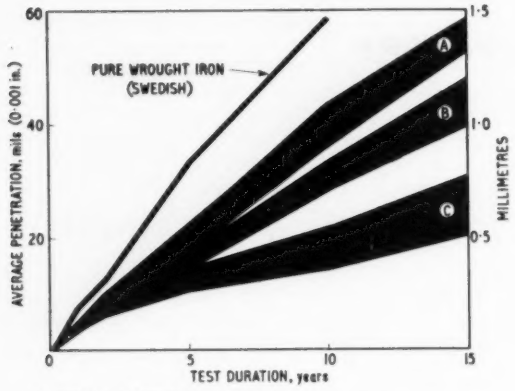
The results of the numerous tests in various climates recorded in the report fall into line with the earlier fundamental conclusions of Dr Vernon, that the intensity of atmospheric rusting is governed mainly by, first, the humidity of the air, and second, the atmospheric pollution.

The effects of atmospheric pollution have been investigated in tests made with the collaboration of the Fuel Research Station, at 16 UK sites, ranging in severity from Godalming to Billingham. As is shown in Fig.2 (p.9) the rate of rusting of steel, and also the rate of corrosion of zinc, were observed to be broadly proportional to the sulphur pollution of the air.

We have found it useful when studying the potential corrosiveness of a given site to draw up diagrams showing the annual variation in relative humidity there. Some typical diagrams are shown in Fig.24 (p.73), where the atmospheric conditions in London, New York, Trieste, and Suva, are compared. They show that the relative humidity at London is considerably higher throughout the year than that at New York. This suggests that the corrosive conditions may be more severe in London than in New York.

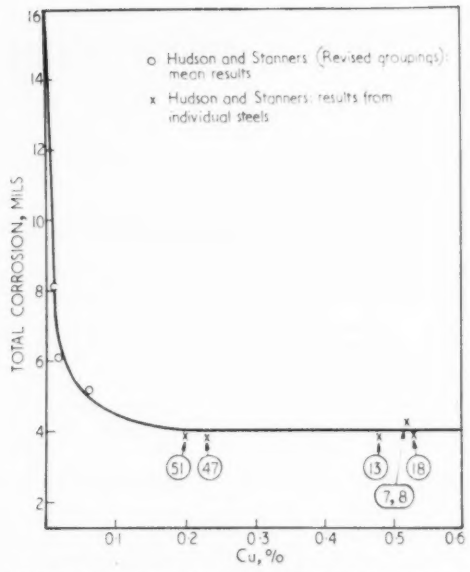
Dr **W. H. J. Vernon,** O.B.E. (late Chemical Research Laboratory, Teddington): Emphasis should first be placed on the characteristic accuracy to which the outstandingly high reputation of Dr Hudson's field tests on behalf of the Corrosion Committee is so largely due. This accuracy encourages more minute study of the papers listed in the Report and makes some amplification possible in certain places. An example is provided by the comprehensive data published by Hudson and Stanners (1955) for steels exposed at Sheffield for periods of up to five years. Detailed analysis reveals (for steels carrying the 'usual' elements but no 'alloying' elements other than copper) a striking confirmation of the 'Buck' relationship between corrosion and copper content (Fig.*B*), even after only one year's exposure. The analysis further shows the relative freedom from scatter in corrosion values from steels of copper content lying between about 0·2 and 0·5% (apparent from Fig.*B*) and (not shown in figure) the increasing degree of scatter (due largely no doubt to an increasing susceptibility to the influence of sulphur in the steel) as the copper content falls below about 0·2%. It confirms the soundness of using as a reference standard in field tests a steel of copper content lying on the near-horizontal part of Fig.*B*.

Considering all steels of the Hudson–Stanners series (most of which carried alloying elements), provided that the steels are arranged in groups of related composition and mean corrosion values plotted, one finds that corrosion/time curves are virtually straight lines after a period of between one and two years. Clearly the slope of the linear branch (inversely related to corrosion resistance) depends on the nature of the corrosion product built up in the earlier period. (The 15-year results plotted in Fig.17 (p.56) for certain individual steels do not bring out the important pre-linear disposition of the time corrosion curve.) Further, when corrosion values of the Hudson–Stanners steels are plotted as ratios of the corresponding mean values of the copper-bearing steels (0·2–0·5%Cu), interesting dispositions are revealed, the general



A unalloyed low-carbon steels
B UK wrought irons; copper steels; Swedish wrought iron (0·6%Cu)
C chromium–copper steels

A *Atmospheric corrosion of wrought irons and steels outdoors at Sheffield*



B *Relation of corrosion (one year's exposure) to copper content of steel*

trends of which, for individual steels, have been pointed out by E. Ll. Evans.[1] A more detailed analysis of the reported values suggests the possibility that a large number of low-alloy steels might be classified in their resistance to atmospheric corrosion within a few fairly clearly defined groups. Much further data will need to be accumulated from representative steels in various locations before this can be firmly established.

In the complementary field of environment, Dr Hudson has suggested (p.72) that 'it might prove possible to assess the corrosiveness of a given atmosphere from records of annual variations in relative humidity and atmospheric pollution'. Various qualifications are quite rightly stressed. Meanwhile the graphical method (Fig.24) of relating meteorological data to the month of the year and hour of the day holds much promise. These diagrams are not merely of academic interest, but of real practical value, perhaps best appreciated from Fig.24*A* for the London area, notwithstanding that as this diagram becomes more generally known by the public and householder the painter's job may become even more seasonal than it is at present.

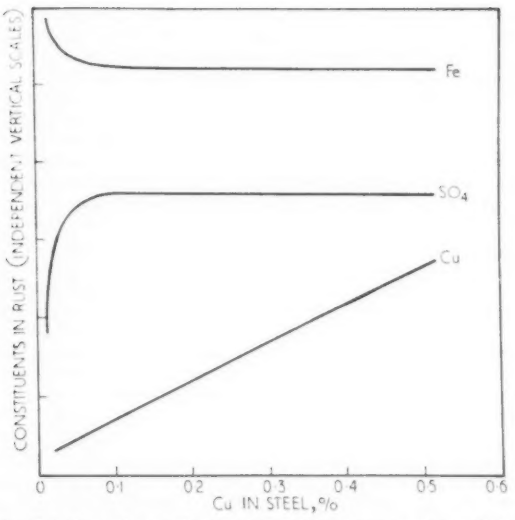
It is startling to learn that the direct relationship between atmospheric corrosion and sulphur pollution (Fig.2), a notable feature of earlier reports, has not been sustained in recent tests (Table XV and p.74). The series of four-year values at Brixham are normal; those at Derby and Sheffield are anomalous. At Sheffield the pollution figures are markedly higher than those of the pre-1953 years, yet the corrosion figures are less; at Derby, the figures, although progressively increasing, lie wholly within the middle part of the sulphur pollution values of Fig.2. The anomaly is therefore not confined to the higher pollution ranges; the situation does suggest, however, that 'other pollutants have come into play' (*see* p.74) within recent years. Bearing in mind that the lead-peroxide method does not distinguish between SO_2 and SO_3, the question arises whether any change has taken place in the relation between these two products. Experimental evidence has hitherto justified the view that under normal conditions sulphur is present almost entirely as the dioxide; as such it is widely dispersed in the atmosphere over the country. It has been shown that at a metal surface, catalytic oxidation to SO_3 will initiate attack, under appropriate humidity conditions. No doubt some of the SO_2 entering the atmosphere undergoes catalytic oxidation by adsorption on finely divided active particles (e.g. carbon, ferric oxide), likewise derived from products of combustion, but this cannot be so widely dispersed geographically. However, the marked extent to which in recent years heavy oil fuel (of relatively high S content) is replacing conventional solid fuel, coupled with the far more complete combustion that normally obtains in the burning of oil, prompt the suggestion that an increasing proportion of SO_3 may make up the estimated total of S pollution, particularly in urban and industrial areas, through the direct emission of SO_3 into the atmosphere.

The matter is obviously of some general importance, notwithstanding that no immediate explanation of the anomalous values of the Report (Table XV) can be offered. More work is needed both on the pollution and on the corrosion side; on the one hand, to devise a practical method of determining the separate amounts of SO_2 and SO_3 in the ambient atmosphere, on the other, to investigate their relative effects on an exposed metal surface, bearing in mind that the action of sulphuric acid already present as such in the atmosphere is not necessarily identical with that of H_2SO_4 produced *in situ* at the metal surface by oxidation of SO_2, catalytically or otherwise. (Neither is there necessarily any parallel with the clinical aspects of SO_2 and SO_3 as present in the atmosphere.)

Finally, gratifying progress is noted in the Report on the examination and analysis of rusts, which is of considerable importance in the elucidation of the mechanism of protection by alloying elements. Many years ago, in the non-ferrous field, I distinguished experimentally between the corrosion product remaining on the metal and that removed by rain. Years later, with E. G. Stroud at Teddington, I attempted to do the same for a series of representative ferrous materials. The experiments were discontinued at an early stage, because of the war, but served to confirm the important part played by rain in ferrous corrosion, e.g. in the building up of a protective complex in the rust on copper-bearing steels as studied particularly by Copson.* The 'neutrality' of copper in the absence of rain is brought out by references (p.11) in the Report, e.g. copper–steel sleeper plates in tunnel (*cf.* excellent performance on open-track), and copper–steel test plates inside a steel chimney. In each case there was no lack of electrolyte on the specimen, but in the absence of rain the beneficial effect of copper was not shown.

The behaviour of copper-bearing steels in the open ('sulphur bearing') air is remarkable if one thinks in terms of the 'Buck curve' (Fig.*B*), not only for the reduction in corrosion brought about by very small additions of copper, but also for the virtually constant corrosion values in the latter part of the curve when 0·2%Cu is exceeded. (This seems to have been taken for

* *Proc. ASTM*, 1945, **45**, 554–579.



C *Relation of constituents in rust to copper content of steel (schematic, cf. Copson, 1935; 6th Report, 1959)*

granted in the past, without explanation.) It is the more remarkable in the light of the evidence now available from rust analyses. Figure *C*, which attempts to integrate this evidence schematically, is based primarily on the curves published by Copson (1945) but incorporates also the findings of the 6th Report, which are in substantial agreement. As will be seen, in that region of Fig.*B* in which increasing Cu content of the steel is accompanied by a virtually constant corrosion rate, there is in fact a progressive increase in the amount of Cu in the adherent rust.

The clue to this paradox is believed to lie (*a*) in the fact that (SO_4) in the rust remains virtually constant as the Cu content increases (Fig.*C*), and (*b*) in the behaviour of copper metal itself in the open (sulphur-bearing) air. Here, the initial product is largely normal $CuSO_4$; this undergoes early hydrolysis, the soluble product of which, with some normal $CuSO_4$, is leached out by rain. ($CuSO_4$ was likewise found in the soluble products from copper–steels at Teddington, in the early stages.) These early effects are followed by the development of a basic copper sulphate, the basicity of which increases slowly with time. The process is believed to be controlled by the co-ordination mechanism of Werner, in the light of which, when the 'primary' valency of copper is satisfied in the formation of normal $CuSO_4$, there remains the 'secondary' valency directed towards building up a complex in which six hydroxyl groups are arranged about a central Cu atom. On this view the formula of the basic copper sulphate may be represented so:

$$[Cu\{(OH)_2Cu\}_x]SO_4$$

Here x has a maximum value of 3; but the protective value of the product (in this case the familiar 'green patina') is established long before that value is reached.

As applied to the Buck curve it is suggested that analogous changes take place within the adherent rust. With Copson, it is believed that the function of the basic complex of Cu is to fill in pores in the rust to give a more compact and more resistant product. However, it is now suggested that the content of copper in the steel determines the value of x, within the period required for the Buck curve to become established. At about 0·2%Cu the value is optimum in the sense that it permits the formation of a complex having the general configuration shown by the formula. At higher contents of copper the permissive value of x increases but the same amount of SO_4 remains fixed by the same amount of Cu; hence amounts exceeding this are used up merely in bringing more (OH) groups within the complex to satisfy the secondary valency.

The foregoing is offered as an explanation of the characteristic shape of the Buck curve, particularly at the higher contents of Cu. Clearly it must be incomplete. It takes no account of possible basic complexes of iron. Any such tendency on the part of Fe alone is known to be weak, but associations with the Cu complex are not ruled out. Neither does it take account of phenomena at very low Cu contents. The presence of $FeSO_4$ in the adherent rust has been shown by Mayne and by Thornhill, the former having given much attention to the dangers of its retention beneath a paint coating. Dr U. R. Evans has studied the electrochemical mechanism of the acceleration of rusting by soluble iron salts and further developments from this work will be awaited with much interest. Indeed, an appropriate note on which to close is taken from a conclusion in the 6th Report itself, namely the need for still more work in this field.

The **Chairman:** Dr Vernon's distinction between SO_3 and SO_2 is receiving increased attention from those who are interested, not in the corrosion of metals, but in other forms of corrosion. I have been in correspondence with the chairman of a medical committee on the matter, and he has told me that they are now taking the difference seriously. I had occasion recently to look through the Beaver Report, and I was surprised to find how comparatively little distinction is made between the two.

Dr Vernon also brought up the fact that the increased use of fuel oil may be the cause of the greater amount of SO_3 present. I wonder whether vanadium in the oil may be helping the further oxidation by catalytic action?

Mr **E. Ll. Evans** (National Chemical Laboratory, Teddington): The Report gives an admirable account of the knowledge gained from more than 20 years' work. Nevertheless, it reveals a number of things we still do not know, and three of them deserve comment.

Dr Vernon has drawn attention to the discrepancy revealed in Table XV. Putting it into the form of a question, we may ask why the corrosion rate at Derby was so high in 1953, when the sulphur pollution was so low compared with Sheffield and with Derby itself five years later? The relation between corrosion and sulphur pollution is not so straightforward as some may believe. We do not know enough about the relation between corrosion, pollution of *all* kinds, and climate.

The next doubt concerns the practical advantage to be gained from using slow-rusting low-alloy steel. Exposed structural steelwork is rarely put into service without painting. Painting may be omitted when the environment is not at all corrosive, or where abrasion would destroy the protection given by paint, but as Dearden and Swindale[2] have pointed out, if abrasion prevents the build-up of rust then a low-alloy steel will show no advantage over a mild steel. It is stated in the Report that low-alloy steels are helpful in preventing rapid breakdown when paint coatings begin to fail. There is also some useful information about railway wagons. But do we know enough about this subject to enable us to help the engineer to make a convincing calculation of likely savings on maintenance?

The third question arises indirectly from the Committee's notable achievement in showing that rust and millscale should be removed from steel before painting. However desirable, this is a costly process. Are we sure that there is no way of making rusty surfaces safe for painting? It is conceivable that the main cause of trouble lies in the saline material found in the rust in polluted atmospheres. It may be possible to remove this by suitable treatment, but if we are to be sure that we are doing the right thing we must know more about the properties of rust in bulk. A search for this information in the literature reveals a gap; most of the work done so far on the *mechanism* of rusting in the atmosphere has been confined to the earliest stages of the process. Vernon's well-known researches[3] have provided an invaluable guide to the prevention of corrosion in storage conditions by controlling humidity and eliminating contaminants. Buckowiecki[4] has shown that the relative humidity at which corrosion can begin is dependent on the hygroscopicity of contaminating salts on the metal surfaces, unless the salts have inhibitive properties. (The obviousness of

this has not been universally appreciated, so the work has been useful.) In the USSR Rozenfel'd[5] and his colleagues have made valiant efforts to study atmospheric corrosion as an electrolyte reaction, but their system is far removed from the one we have in mind, for they consider the ideal early stage at which the metal is covered with a very thin film of moisture.

There is clearly a need for closer study of what happens in and under thick rust layers, and of the mobility and osmotic behaviour of whatever saline material they may contain, and it is gratifying to learn that the Corrosion Committee is turning its attention to this.

The **Chairman:** Mr Ll. Evans has raised many very important points. He asked why it was that, despite the fact that the sulphur pollution in Derby was increasing over about the last four years, the corrosion rate was not increasing.

Suppose we assume that the SO_3 per unit area of the specimens at Derby was increasing, what would have happened? It would have absorbed water (I refer to the non-rainy periods) until the concentration, whatever it was, of H_2SO_4 came into equilibrium with the moisture in the atmosphere. Presumably then equilibrium would result. If that was all that happened it would merely mean that, provided that there was enough of the sulphur oxides, there would simply be a thicker film of acid condensate, but no higher concentration on reaching equilibrium. There is some reason for thinking that a great deal of the corrosion really goes on during periods when there is no rain but moisture and condensation, and that this contains acid.

A friend of mine who lived in North London and had occasion to pass under certain railway arches every day made it a practice to put his finger along the moisture condensed there and then apply his finger to his tongue and say, 'Ah, it is a good brew today!' The acidity varied quite a lot from day to day. I think that we have to consider this condensed moisture a little more than we have done.

Mr **T. H. Turner** (Formerly Chairman of the BISRA Atmospheric Corrosion Sub-Committee, and former Chairman of the SCI Corrosion Group): Much of the discussion so far has dealt with some figures for which I was responsible. Mr Ll. Evans has asked why the corrosion rate at Derby was so high.

From the atmospheric corrosion point of view very little is known about the nature of the atmosphere at any one test site. Ten years ago there were very few atmospheric-pollution measuring instruments of any kind in wide use. In 1951 the British Standard deposit gauges for atmospheric pollution, for which I was responsible, came into use and there are now over 1 000 of them giving data in this country. A week-long International Conference on Clean Air is imminent; the subject is now recognized as sufficiently important to bring together about 1 200 people from all over the world.

It was, therefore, atmospheric pollution as well as atmospheric corrosion which caused me to ask for the deposit gauge responsible for the figures now under discussion to be erected near my former office. Significantly the site is in the dirtiest industrial square mile of Derby, close to the big gas works and much troubled by grit, some of which comes from the pulverized coal-burning furnaces of a foundry.

Dr Vernon's early work has taught us that such solid particles increase the corrosion of metal surfaces on which they are deposited. Examination of the test figures from 1952 to 1956 show that there is an abnormal amount of grit at this test site. The grit consists of porous fritted particles that concentrate sulphur-bearing fluids, which they contact in the air, through the diurnal changes in temperature and pressure.

Owing to the Clean Air Act the amount of grit at this test site shows signs of decreasing but the SO_2 figure has doubled, apparently because the gas works has erected big new vertical retort-houses, using sulphurous coke breeze as their fuel. More exotic chemicals in the atmosphere may be affecting our corrosion test figures but at present we can only refer to the grit and SO_2 figures.

Mr Ll. Evans also asked: Where do we go from here? It seems that corrosion research should now couple abrasion and corrosion, as often happens in service and has been investigated in a novel piece of work reported to The Iron and Steel Institute in a paper by Dearden and Swindale of British Railways Research Department.[2]

Another feature in the 6th Report on which I should like to comment, because it has occupied me considerably when Chairman of the Low-alloy steel Panel, was recalled by Fig.3 (p.10) of one of the 100 LNER coal wagons in which the behaviour of four different steels was tested for 15 years on end. This is surely one of the best-documented, long-term, practical investigations of corrosion in service. The publication of Dr Hudson's figures in this case is doubly timely because the European railways have recently introduced internationally standardized wagons. These may be built and repaired in any country and they wish to standardize some steels with enhanced corrosion resistance. So far as I am aware, no one can refer to better practical comparisons of low-alloy steels with mild steel than those reported by the BISRA Corrosion Committee.

Mr **J. F. Kayser** (Gillette Industries Ltd): In spite of the work that has been done during the last 15 years it is an unfortunate fact that the probability that cold-rolled steel or a motorcar body will corrode is, if anything, greater than it was in 1939. In so far as cold-rolled steel is concerned I have had a unique opportunity of keeping large quantities under observation for at least the last 30 years and in so far as motorcars are concerned I can only refer to my own cars. For several months I used a pre-war car and a post-war car alternately, and unfortunately after three months the roof on the post-war car showed more signs of corrosion than did the roof of the pre-war car.

I should next like to take this opportunity to protest against results being expressed as averages. When I was in the steel trade I had a small melting furnace and the average temperature from one end to the other was about 800°C. Everyone will agree that it would be ridiculous to say that steel melts at an average temperature of 800°C. With great diffidence I would refer to a recent communication of Dr Hudson in which he wrote that the reason the Delhi pillar does not rust is because the average relative humidity at Delhi is only 46%. For a significant period each year the relative humidity in the Delhi district is in excess of 80% and it is then that atmospheric corrosion takes place at a rate that is never encountered in this country. Having carefully examined the Delhi pillar I am in a position to say that it is a rusty column of metal. The rust does, however, adhere very strongly in the same way that it adheres to many harbour bollards and cannon and other articles that are distributed widely around our countryside.

One of the most important experiments in corrosion technology was Vernon's butter-muslin experiment and I do think it would be worth while to seek an explanation for the phenomenon he reported. I have had small pieces of steel under microscopic examination for long periods and have observed that the probability of a particle of dust becoming a nucleus for corrosion is very small indeed; but there are very large numbers of particles of dust on a steel surface that is freely exposed to the atmosphere. So far I have been unable to differentiate between particles of dust that form a nucleus for corrosion and those that do not, but I have been informed that it may be owing to the electrical charge originally carried by the particle and I would be interested in any work that has a bearing on this.

Dr **J. B. Harrison** (Goodlass Wall and Co. Ltd): My contribution may be of practical interest to Dr Hudson and his Corrosion Sub-Committee. I am concerned with surface coatings rather than with atmospheric pollution, but four years ago my laboratory decided to start assessing primers on rusty steel. My friends and foes alike advised me that I was entering a very treacherous field, and their main argument was that lack of repeatability on the substrate would invalidate the results.

We tried to be as careful as we could by deciding to start with autobody steel sheet one month rusted on the laboratory roof north-west of Liverpool. We immediately confirmed that the time of the year was a very pertinent factor in the viciousness of the substrate. To that end, at various periods we acid-pickled the rust off with nitric acid and tested the contaminants in the rust. Naturally, at Liverpool we always obtain a very positive test for sodium chloride, so positive that it can actually be measured gravimetrically. Traces of sulphur were always found. At that stage we wanted to know which was the most potent contaminant, and to that end we put on a simple series of tests in which we took pieces of the same steel sheet and swabbed with 5% solutions of ammonium sulphate, sodium sulphate, sodium chloride, hydrochloric acid, and sulphuric acid respectively, allowed them to rust for one week under cover so that the contaminants were not washed off, and then with a bright steel control we coated with one coat of the same primer on top and exposed them in exposure racks.

It was found that acids as rust promoters, from the point of view of effect on primer, are in themselves quite innocuous. A good-quality primer will give the same performance on such rust as it will on bright steel. The most important result was that ammonium sulphate was by far the most vicious contaminant, much more so than sodium chloride and sodium sulphate.

May I suggest that the researches in the past have neglected the part played by the ammonium radical? Billingham, which has easily the highest corrosion rate, also makes fertilizers. I would therefore suggest that one is almost sure to get deposition of ammonium sulphate. I was also struck by the fact that the copper-alloyed steels obviously reduce the corrosion in a given environment. Copper and ammonia are mutually attractive. Is a possible explanation of the increased corrosion resistance of the copper-alloyed steel that it reduces the potency of ammonium sulphate surface contamination by the coordination of the ammonium radical with the evolution of comparatively mild sulphuric acid?

The **Chairman:** We are grateful to Dr Harrison for these important points and the results of his simple but very effective tests. Ammonium sulphate is important, and I think this has been realized by people connected with the Committee, although it may not be mentioned very much in the Report. Some of Vernon's earlier reports mentioned ammonium sulphate, and I certainly remember that the Atmospheric Tests Sub-Committee used various accelerator tests in which specimens were made to pass round a cycle, generally attached to a moving band, and coming under various sprays; one of the liquids which was favoured for use in the spray bottles was compounded on the basis of Vernon's results and contained ammonium sulphate, and, I think, among other things sodium chloride.

Dr **Harrison:** On the basis of the coating and the primer, I assessed the viciousness of ammonium sulphate as probably 50 times that of sodium chloride.

The **Chairman:** Somewhere it has been stated that SO_4 and Cl together may be more vicious than either apart, but not, I think, in connexion with ammonium sulphate.

Dr **Vernon:** Mr Kayser's remarks prompt me to comment on what appears to be a common misconception in the use of the word 'dust'. The dictionary defines it as that which is thrown up from the ground and carried around by wind. Such particles, if one excludes wind-borne sea-salt, are probably the least corrosive towards bare metal. The dispersed particles most commonly responsible for corrosion must derive largely from atmospheric pollution, often indeed from reactions going on in the atmosphere itself, of which ammonium sulphate, mentioned by Dr Harrison, is a conspicuous example. Another important factor is the extent to which the air-formed oxide film has been able to build up on the metal surface before it makes contact with these finely dispersed particles.

Dr Harrison's remarks remind me of a point I should like to put to Dr Hudson as to the effect of sulphate pollution and chloride pollution action conjointly. My impression is that the effect is often more than additive, but Dr Hudson's views, from his experience, would be welcomed.

The **Chairman:** Recently we have done some work not yet reported, at Cambridge, in which one of the methods of work has been to stamp on bright steel specimens patterns of lines forming a sort of chessboard, to paint them, expose them to the atmosphere and, in other cases, over water, and allow them to develop rust. Very often rust with some salts will appear in the lines even though the squares between them remain entirely bright. These experiments bear out Mayne's observation that very small traces of ferrous sulphate in rust are very important.

I have been studying the mechanism of the cause of ferrous sulphate in catalyzing fresh rusting and I am fairly satisfied as to what is the cause. It explains why one gets breaking-down of paints at places where the paint has been applied over rusted surfaces at certain places which are 'nests' of ferrous sulphate. There, the paint will be pumped up by fresh rust formed, and then break down in the ordinary way, forming star-shaped cracks, so that protection fails. It is not possible to go into this in detail; we are not sufficiently sure of all the facts, and there is not time.

Dr **Hudson,** in reply: I will deal with three major points now, and reply to the others in writing.

(1) Several speakers, including Dr Vernon, have stressed the importance of atmospheric pollution, and pointed out certain anomalies in the records for the Committee's test sites. We are aware of these anomalies, but we do not regard it as our function, or have not done so hitherto, to specialize in the study of atmospheric pollution. We have considered it sufficient to use the generally accepted methods developed by experts in this field, notably the Fuel Research Station. It has now become apparent that, for use in connexion with atmospheric corrosion investigations, more detailed methods of measuring pollution are required. A distinction between the sulphur dioxide and sulphur trioxide in the air seems desirable. Moreover there is a need for simple methods of determining chloride pollution similar to the sulphur candle used for sulphate pollution.

(2) The discussion about painting over rust has strayed into this session from the next one. I have every sympathy with the view that it is most desirable to find a practical means of doing this, but frankly I regard the conception as unrealistic. Most forms of rust are damaging to paint performance, and I feel that it would be extremely dangerous to dangle before our engineers the attractive possibility that it is generally safe to paint rusted surfaces. After some 30 years of strenuous endeavour, we have at last persuaded them to adopt the safe course of removing rust and millscale entirely from their structures before painting them. I think it would be most injudicious in the present state of knowledge to make any suggestions that might lead them to think otherwise.

(3) Mr Kayser's remarks about averages are pertinent and correct in doctrine. The scientist should not restrict himself to mean values but take into consideration the distribution of results. Actually this is the course that I adopted with regard to the Delhi pillar, although I may well have stated when writing to Mr Kayser that the relative humidity there averaged 46% throughout the year.

Since this statement would be consistent with, say, a relative humidity of zero for six months of the year, and of 92% for the other six, Mr Kayser's criticism is valid at first sight. However, if reference is made to my original letter to *Nature* on the subject (*see* ref. A 8071, p.154), it will be found that monthly averages are given for the whole year, and that at most periods the relative humidity is below 70%. Indeed, I am now endeavouring, with the assistance of Indian friends, to obtain hourly values for the humidity at Delhi.*

* These have since been obtained and are given in Dr Hudson's written reply, p.349.

Session II Discussion on protective coatings

The **Chairman** (Mr L. Kenworthy) introduced Dr **J. C. Hudson:** This session is to be devoted to the Committee's work on protective coatings, including that carried out during the war on anti-glare structures. In this case we reached the conclusion that the only coatings that might have proved useful under the extremely difficult conditions in question were vitreous enamel and heat-resisting aluminium paint. Unfortunately the prevailing shortage of these materials precluded their use. We therefore suggested that thick steel sheets should be used and replaced after destruction. By then, however, the problem had become less acute, because the managers of the coke ovens and other plants concerned had found means of reducing the intensity of their corrosive conditions very considerably.

Throughout the lifetime of the Corrosion Committee, the use of sprayed metal coatings, notably of aluminium and zinc, has increased considerably, with great advantage to the structural-steel industry. It may be that the investigations of protective metal coatings described in the Report have helped in this development.

Considerable attention has been paid to the protective painting of structural steel. It may be useful to summarize the Committee's findings with regard to the main factors that affect success. These are:

(i) composition of the basis metal
(ii) surface preparation
(iii) nature of the painting scheme: composition; thickness
(iv) ambient conditions at the time of application
(v) climate in which exposed.

(i) Although on occasion a correlation has been observed between the corrosion resistance of the basis iron or steel itself and the life of a painting scheme applied to it, in general the effect of the composition of the basis metal on paint performance does not seem to be marked. For example, at most of the Committee's ten or more test sites in different parts of the world, the lives of paints were substantially the same on ordinary and on copper-bearing steels. The use of low-alloy steel for a painted structure is of practical value, however, because it reduces the corrosion rate when the paint has failed, and thus provides a safeguard if maintenance falls into arrears.

(ii) Good surface preparation is the most important single factor towards successful protective painting. To obtain the best results the priming paint must be applied to a perfectly descaled surface free from rust and millscale.

Here I might usefully amplify my comments (Session I) about the possibility of painting over rusty steel. We must distinguish clearly between painting over rusty steel and painting over rusty steel plus millscale, which is an entirely different matter. For example, Dr Harrison said that he had conducted some experiments on autobody steel sheet. Presumably this sheet was bright to start with, and it would certainly carry no millscale. Consequently, in his experiments he would obtain a surface on which there was light rust but no millscale. Such a surface is much less damaging to paint performance than one on which both millscale and rust are present. The heavy plates and sections that are used to build structures like the Forth Bridge are produced by hot-rolling, and they leave the mill with an oxide scale on their surface. I firmly believe that the only satisfactory procedure is to remove this millscale by pickling or gritblasting. Attempts to get it off by allowing the steel to rust to some extent and then hand-cleaning the surface generally result in inferior paint performance, because unless prohibitive cleaning costs are incurred, some broken millscale is inevitably left beneath the paint. Consequently, although I have an open mind as to whether it will be possible to develop paints suitable for use over lightly rusted steel free from millscale, I think it will be a long time before we can find a paint of a normal type that will give good results over weathered surfaces of heavy structural steel.

(iii) Two factors are involved in the nature of the painting scheme. The first is the composition of paints themselves, and the second the thickness of the dry paint film. It is now generally agreed that an inhibitive priming paint should be used. The best known type is red lead in linseed oil, but there are numerous alternatives, e.g. paints pigmented with zinc chromate.

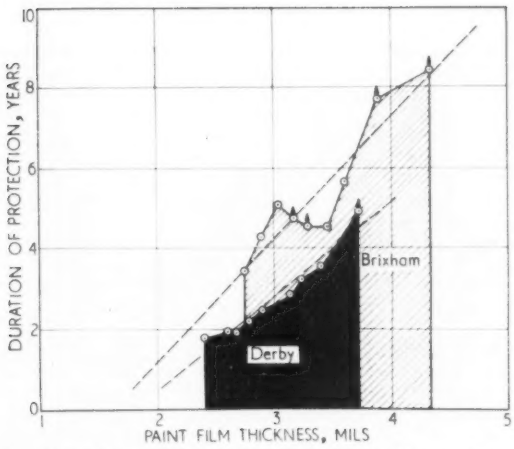
The choice of the paint medium should be matched to the method of surface preparation. Where the old-fashioned procedure of weathering and wire-brushing is followed, it is difficult to improve on a red lead in linseed oil primer. A much higher grade of surface preparation is essential if full advantage is to be taken of the valuable properties of the newer paint media that have been introduced within the lifetime of the Corrosion Committee. Here pickling or gritblasting must be used, for it is a waste of time and money to put these paints on to poorly prepared surfaces.

It is equally wasteful to apply paints at inadequate film thickness. This is evident from the results plotted in Fig.*D* which relate to 100 painting schemes exposed at Derby and Brixham. There is a broad proportionality between dry paint film thickness and duration of protection, and it is clear that paint films less than 2 mils thick will generally have little protective value. For structures erected in the UK it is wise to aim at a minimum thickness of 5 mils.

(iv) Further study is needed of the effects of the ambient conditions at the time of painting, or more precisely, of how to counteract them when they are adverse. There is a world of difference between painting small specimens in a laboratory, and painting a structure in the field. The contractor who undertakes to paint a large gasholder, for example, may be at the mercy of what happens in neighbouring blast-furnaces and coke ovens, quite apart from the changes in weather conditions. Not only do we need paints that can be applied over rust if desired, but also paints that are less vulnerable to adverse circumstances, and which can be put on even in pouring rain or a haze of smoke. Indeed, the choice of a paint will sometimes be governed by its ability to dry in a difficult environment rather than by its absolute protective value as judged by a straightforward trial under good conditions.

(v) The results plotted in Fig.*D* show that there is less difference in paint performance at Derby and at Brixham than might be expected, considering that Brixham has a clean marine atmosphere but Derby a heavily polluted industrial one. The high degree of atmospheric pollution at Derby, which accelerates the corrosion of bare steel, also decreases the amount of sunlight, so that the breakdown of the paint film itself through irradiation proceeds more slowly. It would, however, be unwise to generalize about the effects of climatic differences on paint performance but they do not necessarily correspond with their effects on the corrosion of bare steel. Particular factors may come into play. For example, in hot and humid climates overseas the rate of paint breakdown may be greatly increased by the growth of moulds and fungi.

Dr **L. A. Jordan,** C.B.E. (late Paint Research Station, Teddington): The picture presented of the basic principles of corrosion is valuable and accurate, but perhaps not extensive enough. It is apparent that there are features, concerning thickness of coating in particular, which are very much more important than has been indicated. Three, four, and five mils were taken as normal thicknesses. Why should one not put on 20 mils? Dr Hudson speaking of US practice said that there a thinner coating than in the UK was acceptable. I am not sure that this



D *Effect of film thickness on the protection of steel by paint*

is true, at any rate in the US there are some advocates of putting on very much thicker coatings. I know of one firm doing very good business indeed in dealing with miles of electric pylons and a very considerable number of gasholders and similar equipment, and they advise putting on 20 mils. With such thick coatings the composition is less important.

The section of the Report dealing with anti-glare devices is a short one and refers to the wartime problem of coping with anti-glare devices at steelworks. The maintenance of these anti-glare devices, i.e. securing a life of months instead of weeks or even days, in adverse conditions of high temperatures with vast quantities of steam heavily polluted with sulphur gases, was extremely difficult. The only possible solution was adopted, i.e. to cover the glare areas with iron or galvanized iron sheets and to try to keep them from corroding away too soon. There was much to be said for using heavier gauge sheet than usual and letting it go to destruction without protection beyond the initial painting.

Certain points strike me as being of interest:

(i) Vitreous enamelling did fairly well on the whole, but at considerable cost.

(ii) Galvanizing alone was unexpectedly bad. The zinc coating cracked and peeled away under the stresses imposed by alternate heating and cooling. It usually misbehaved when functioning as a base for other coatings. Some of the failures of paint coatings would no doubt be due to the notoriously bad adhesion of such films over crystalline zinc.

(iii) Silicate coatings consistently failed.

(iv) Except in those situations where conditions were not too severe and the temperature did not exceed 150°C, most of the various media failed. However, three or four gave fairly good results, e.g. an aluminium paint in a synthetic medium (which was not defined but which would almost certainly be a phenol/formaldehyde resin-type base), two graphite stoving paints, and a paint carrying micaceous iron ore (also presumably in a phenol/formaldehyde resinous medium) over a chromate primer.

(v) The limited references to sprayed aluminium and sprayed zinc metal coatings are favourable. Indeed, they are described as being the only coatings at Bilston roof level left in good condition after 215 days; such is the sort of time level throughout this Report.

In case (iv) it is probable that the organic medium burned away or that at most it left little more than a carbonaceous residue; but under such conditions aluminium pigment could have sintered on to the surface of the sheet. It is known that this happens quite readily with aluminium paint on steel chimney stacks and on the exhaust manifolds of cars. Even so, it is surprising that such a thin film of metal of rather uncertain quality film-wise should provide protection under such aggressive atmospheres.

It was also noted that a thin film of linseed oil made quite a reasonable showing. That sort of behaviour has been noted before with linseed oil, especially when applied to hot metal. Under these conditions, however, it probably left not more than a finely divided carbon residue, but it might have been laid down in such a way as to have developed into a very resistant skin, and when the temperature was high enough it might have had a case-hardening effect.

The other general conclusions that should be noted are:

(i) With experience, much improvement was obtained in performance by improving the ventilation arrangements and by localizing the worst corrosive effects. Briefly, this means taking steps to mitigate the severity of the corrosive conditions.

(ii) Copper-bearing sheets showed no significant advantage over other types.

(iii) Hot galvanized coatings were definitely not satisfactory.

(iv) The most effective paint consisted of leafing pigment: as aluminium, in a synthetic (phenol/formaldehyde) medium.

(v) Below 150°C the difficulties could be resolved, in the sense that reasonable painting schemes would have sufficed.

Finally, the Report says that it would be desirable to conduct a more systematic investigation in this field in the light of more recent knowledge. Thinking in terms of steel covered with non-ferrous metal, the coating would probably be applied by spray gun. As there are other processes, e.g. electrodeposition and galvanizing, they would all need to be considered in terms of such matters as limitation to factory operation, the need for specialized equipment, and overall cost. Before the metal spray there would need to be some consideration of surface preparation and possibly treatment with phosphoric acid or tannin. There may also be some argument as to whether the non-ferrous metal should be zinc or aluminium, and there is some case for using a mixture of the two metals.

Having got the skeletal framework of a non-ferrous basis metal, which is the first thing to think of, it must be filled quickly with appropriate material. I recommend etch primers, knowing of very satisfactory work that has been done with that kind of filling, but there is no doubt that non-ferrous applications by spraying or any other way must be developed further.

Some users are turning to non-metallic coatings, e.g. nylon, thiokol, and various other related materials. Some of these organics, notably cellulose acetobutyrate and polythene, can be coated as powder by fluidization applied through a porous bed agitated with air at high speed but low pressure. The steel sheets to be coated would be preheated to 180–200°C before being passed through the fluidization tank. The powder adheres and fuses to a smooth surface.

It has been reported that in the USA some new alloys have been developed for application to steel. These alloys are mixed metal powders by which copper and metal are applied to the steel by being fluxed in metallic lead, and seem to be effective.

Dr **T. P. Hoar** (Cambridge University): I am most impressed by many of the results in the Report, particularly some of those concerned with paints. At the same time, Dr Hudson would probably agree that the work on paints is incomplete in that great emphasis has been given to priming coats and little or no emphasis to top coats. I think it is a great pity that the matter has not been taken further with regard to top coats. It is all very well to try out various primers on steel, and put one particular top coat on; but particular primers and particular top coats must be considered together. Equally, if the primers are applied to zinc- or aluminium-sprayed metal, then it cannot be assumed that the best primer is that which gives the best results with one particular

top coat. A different top coat might easily place the primers in a different order. Protective schemes must be considered *as a whole*.

Dr Jordan sometimes refers to metal-sprayed coating as a 'skeletal' coating which will 'mop up' the paint. He did not today say what sort of porosity he was thinking of in the metal-sprayed coating, but I have heard him on other occasions refer to 80% porosity. I do not believe that any metal-sprayed coating ever has a greater volume porosity than of the order of 20%, and that is unusual. Most of the wire-sprayed coatings, when examined metallographically or by density, seem to have a porosity of about 12% maximum and the powder-sprayed coatings of up to 17%. To call these 'skeletal' coatings is excessive, and although undoubtedly such a coating acts as a good key for paint, it does not mop up quite the amount that Dr Jordan would wish.

Dr **Jordan,** in reply: In point of fact it does. It may be that the paint layer is a bit on top of the sprayed coat; it is not all entirely due to porosity, but the fact remains that sprayed metal is a good outlet for paint.

Dr **Hoar:** I think we will not quarrel on that.

I notice that a great number of people have had some hand in the tests of the Corrosion Committee over the last 30 years, yet BISRA has investigated only the very narrow field of the corrosion of ferrous metals. There is no mention at all in the present Report of work by Dr Hudson and his team on stainless steels; only one mention of some work on inhibitors; no mention of attack by water and steam on steel at high temperatures; nothing on attack by acids; nothing on cathodic protection; nothing on the influence of sulphate-reducing bacteria; nothing on stress-corrosion cracking and corrosion fatigue; and nothing on corrosion under conditions of radiation. It seems to me that the effort has been on a very minor scale, less than that which prevails in any fairly large US steel company. This is in no way a reflection on Dr Hudson and his devoted team, which I think is far too small and always has been, but it is a reflection on ourselves as a Committee for not having pressed a great deal harder for really comprehensive investigation of ferrous corrosion problems by the body that should be undertaking it on a large scale.

Dr **Jordan:** Once there is a good 'bottom' or primer on steel it will last for a long time, particularly in these days because of the extended use to which non-ferrous spray coatings are applied as part of the basic background of steel protection. The 'bottom' can be maintained by restoring what is lost by abrasion, erosion, or weathering conditions every two, three, or four years.

I mentioned earlier the question of pylons. Pylons are an example of a kind of application of steel which has a very serious limitation. The owners of the pylons cannot afford to put them out of action for days at a time while they are being repaired. In the USA Dr J. S. Long has devised a composition which is proving extremely attractive for pylons and similar things which must be protected, although not at frequent intervals. This particular composition is of white-lead and zinc-metal powder and aluminium powder, worked up in plain linseed oil, and develops a highly thixotropic condition. It is not visually attractive, but it sticks on effectively. He claims that with such a composition he can put on with a 6-in. brush as much as 20 mils thickness of coating at one time. The formula used was: 8 lb of zinc metal, 5 lb of dry white lead in oil, 2 lb of aluminium paste in mineral spirit 55%, and 4½ lb of alkali-refined linseed oil. With that composition anything between 8 and 20 mils thick can be applied at one go. It is neither attractive nor decorative, but nevertheless substantially effective in the job. For practical purposes there is much to commend it.

The **Chairman:** I wonder whether there are any disadvantages in the very thick coating. Would it not be possible that a good deal of porosity would occur with such a coating?

Dr **Jordan:** It does not, strangely enough.

Dr **F. Wormwell** (National Chemical Laboratory, Teddington): Dr Hoar made the point that Dr Hudson had not had the resources with which to carry out as broad a programme as was desirable, and I agree. Many of us have expressed that view in the Corrosion Committee, and the Committee has done what it could to impress that view on the higher body that decides on the resources, but without much success.

One further question that might arise is this: to what extent is it important to investigate the corrosion of bare steel, when through the work of Dr Hudson and others we now know so much about the best methods of protecting steel, and, so far as ordinary steels are concerned, it is recognized that wherever they are used in structures they must be protected?

Mr **C. T. Wilshaw** (F. Perkins Ltd): This otherwise admirable report deals almost exclusively with structural steel and ship's plating. A large proportion of the production of steel and cast iron goes into the manufacture of consumer and semi-durable goods, such as vehicles, agricultural appliances, internal combustion engines, and domestic appliances. Scant attention has so far been given by the Committee to the protection of work of this character, which poses problems different from those encountered in heavy industry.

Apart from an assessment of the relative merits of various protective schemes, there is the question of compatibility of different methods of protection with one another. The manufacturer of an internal combustion engine may be making a product which is used in road vehicles, agricultural appliances, or for marine purposes. He cannot afford to apply to the whole of his production the standard of protection which would be necessary to cope with the more adverse conditions. The end usage of the engine, however, may not be determined until the later stages of assembly, therefore any additional protection required for a marine engine must be applicable to primed castings, to bare ferrous and non-ferrous metals, and to various finishes already applied to some of the sub-assemblies and accessories. Some parts of the engine may have the additional protection afforded by zinc or cadmium plate, zinc-rich paint, chlorinated-rubber paint, etc. (depending on the nature of the component). It would be useful to know, not only which of such high-duty protective schemes behave the best but which are most compatible with a finishing paint that will give good general protection.

Dr **C. Edeleanu** (Tube Investments Research Laboratories, Hinxton): I feel that there are two topics on which Dr Hudson could probably give us some guidance. There is now a great number of temporary protective coatings generally based on linseed oil and it is not very easy to appreciate from the trade literature the advantages of the various types. If he could classify these products and give us some indication of what it is reasonable to expect from them, I think he would help a great many people.

The second topic concerns the use of the very thick solventless coatings which are now becoming available commercially. I have in mind the epoxy resins and coatings based on isophthalic esters which are used allegedly successfully not only to prevent corrosion but to avoid damage due to cavitation, and are alleged to be mechanically very strong especially when reinforced with suitable fillers such as glass fibres. These coatings are often suitable when solvents or caustic soda are involved and an independent view on the potentialities would be of very great general interest.

Mr **R. E. Mansford** (Metallisation Ltd): Much of the work done by BISRA has indicated where a particular coating is of most value. The results of the tests at Sheffield emphasized the value of sprayed aluminium in industrial atmospheres, and have been borne out in practice in the Abbey Steel Works, and similar large projects, but in some instances sprayed aluminium has not been so effective, e.g. in railway tunnels, and the Billingham Chemical Works.

It seems there is modification of the corrosion product formed on the aluminium coating, and it has been suggested that the combination of chlorides and sulphur oxides is to blame. In investigating this, sprayed aluminium coatings on steel were exposed to combinations of HCl and SO_2, or to salt spray and SO_2. Although there was some acceleration of the attack, the breakdown of the coating that can occur in chimneys, tunnels, etc., did not occur. It was found that NH_3 and SO_2 did form a much less protective corrosion product, and this supports the remarks made by Dr Harrison earlier in the discussion.

I should like to support Dr Hoar's comments on sprayed metal and paint coatings. The frequent time-lag between the application of priming paint, and the paints that are to follow must be borne in mind. In practice it may be many months, and in some cases even a year or more, before the final paint coatings are applied. A sprayed metal coating is particularly valuable in such conditions.

Dr **U. R. Evans**, F.R.S. (Cambridge University): One of the advantages of spray coatings is that they are porous and the outside paint coat keys in nicely. There is some evidence that the pores do not reach the steel basis; at least it is difficult to explain their behaviour otherwise. Even without any paint on top, sprayed coatings provide considerable protection.

Dr Jordan mentioned the advantage of using certain very thick coats. I agree with him that the more paint you put on the less it matters which paint is chosen; conversely, the less you put on, the more it matters what is chosen; carrying the argument to the limit, we conclude that if there is going to be no paint at all on certain points, it is highly important to choose correctly the paint for the main area.

There is a far bigger choice of paints which protect at gaps than is generally imagined, and the real limitation, brought out by Mr Wilshaw, is compatibility with outer coatings; we must find an outer coat which does not interfere with the gap-inhibitive properties of the inner coat.

Protection at gaps is nothing new. Many people seem unwilling to believe in cathodic protection at gaps; they say that crevices in the coating are just becoming sealed up with rust or dirt. That explanation does not cover the facts. Often the gap is enormously broader than the thickness of the coat, and the immunity of the exposed steel cannot be explained by clogging.

The electrochemical mechanism of corrosion is pretty well understood, and, despite certain points which are under discussion, general agreement has been reached. But few attempts have been made to use that knowledge in connexion with protective coatings or other methods of protection. If one can design a paint which will keep the potential of the steel exposed at a gap either in the immunity region or in the passivation region of the Pourbaix diagram, it should escape rusting, irrespective of the coat thickness. There may be other reasons, e.g. resistance to erosion, demanding thickness as such.

Dr Hudson has emphasized the good protection obtained with paints containing Burntisland red, which is a bauxite residue, but he suggests (6th Report, p.205) that, if necessary, Indian red to specification BS305 (1952), type I, could be used. The good performance of bauxite residue is probably explained by its derivation from an industrial alkali, so that ferrous sulphate must be absent. Dr Mayne has shown that nests of ferrous sulphate in rust below paint stimulate fresh production of voluminous nests, so that the paint coat is locally bulged out and finally breaks. The same thing happens if the ferrous sulphate is present in micro-crystals between paint and steel; I have recently been studying the mechanism. Almost certainly ferrous sulphate in iron-oxide pigment would have the same effect, and the amount needed to cause trouble is probably small. I am not convinced that the maximum quantity of soluble salts permitted in the specification is sufficiently low to guarantee immunity from the trouble; pending more detailed information, I would prefer a bauxite residue to an Indian red; although many Indian reds obtainable commercially are satisfactory, I can envisage a product which would comply with the specification and yet give poor results.

Dr **Jordan:** We are really concerned with trying to influence the progress of BISRA in its future work, and I am not going to dissociate myself from the importance of that aspect; but the fact remains that on this thin-film approach there are very many problems. I favour the more practical approach, and at the moment thick films go a long way towards meeting the practical requirements.

Expressed simply, however much there are inhibitive pigments in the primer, etc., nevertheless the thin film provides no effective barrier, or only a limited effective barrier, against corrosive elements of the atmosphere, particularly water and more particularly water associated with salts. By contrast, the thicker the film the less do atmospheric factors matter. With a thick film, there is no worry about the access of water, because it does not penetrate. In short, the considerations necessary with thin film, e.g. inhibitive pigments, need only remain in reserve.

Mr **E. D. Dolan** (The British Petroleum Co. Ltd): What does Dr Hudson consider the best painting system for metal-sprayed zinc on steel structures exposed to tropical marine conditions, but not immersed? At present we are sealing the zinc with an oil-based calcium plumbate primer, followed by an undercoat and finish coat of alkyd type paint.

Regarding thick-film protectives, we are very satisfied with an epoxy mastic which is now available in the UK. It may be applied by brush or trowel at a minimum thickness of 10 mils per coat. Our main use is on one-coat work in salt water immersion, normally supplemented by sacrificial anodes of zinc alloy.

The problem of protection of steel chimneys is not yet solved. In our experience metal-sprayed aluminium with a sealant is the only effective long-term protection, but is expensive. I am sure that industry in general would welcome Dr Hudson's guidance in this sphere.

Dr **Hudson,** in reply: I am sure that the Corrosion Committee will agree with Dr Hoar and Dr Wormwell on the wisdom of scrutinizing its research programme from time to time. In point of fact, the Committee has done this at intervals throughout its existence, by devoting special meetings to the subject. We must remember, however, that the amount of work that can be undertaken is limited by the resources available. Dr Hoar's and Dr Wormwell's plea is for an augmentation of these resources, and I think it improbable that they intend any criticism of the Committee. If they do, I would make the point that is often made by historians: namely, that the actions of a given person or organization should be assessed in the light of conditions that prevailed at the time and not in that of those that developed subsequently.

This line of thought leads me to Mr Wilshaw's comment that a large proportion of the steel production is not used for structural steel but for consumer goods. I have spent some time in endeavouring to ascertain how the UK steel output is used and will refer to this in my written reply. Meanwhile we may note that iron and steel products fall into two broad groups: heavy structural steel, which is hot-rolled; and light-gauge steel, much of which is cold-finished. When the Corrosion Committee began its work in 1928, the most intense corrosion problems were those affecting the heavy structural steel side of the industry, and for that reason the Committee concentrated its studies on the protection of structural steel. On the whole the position has not altered greatly over the years. The problem of protecting light-gauge products is generally more specialized, and in some ways easier to solve. A motor car, for example, is a much smaller article than a railway bridge. It can be phosphated and stove-painted in parts, or indeed, if desired, in one piece. It would be difficult to apply these processes to heavy structural steelwork.

Dr Edeleanu enquired about the merits of epoxide resin

coatings and other new products. Most of these are proprietary materials, and their composition is not stated, so that it is difficult to know how to assess them. There are disadvantages in having to use proprietary materials, and it seems to me that we have not gone far enough in drawing up paint specifications and specifications for painting procedures. I feel that the British Standards Institution could help considerably by extending their work in these fields, for as yet apart from certain codes of practice, there are no generally accepted standards. On the other hand, there is some force in the argument that too much standardization tends to discourage private enterprise and impede development.

The question asked by Mr Dolan as to what is the best priming paint or painting scheme for use on sprayed zinc immersed in sea water is one to which an answer is urgently needed. In the absence of any experimental evidence, I hesitate to express a detailed opinion, but I may refer again to the matter in my written reply.

Session III Discussion on marine corrosion

The **Chairman** introduced Dr **Hudson:** The Committee's studies of marine corrosion have been concerned with both the corrosion of bare irons and steels when immersed in sea water, and the protection of these metals against sea-water attack. As little reference is made in the Report itself to work under the first head, I might usefully state that the results have shown that within the usual limits of low-alloy steel composition, the analysis of a steel does not markedly affect its corrosion rate. The superiority of low-alloy steels over ordinary mild steels in respect of resistance to outdoor atmospheric corrosion is not paralleled under conditions of total immersion in sea water. The addition of something like 3% of chromium, which halves the corrosion rate but takes the steel out of the low-alloy steel category, is needed to bring about a worthwhile improvement in the latter case.

A great deal of the research on protective coatings has been done in collaboration with the Admiralty. It has led to the development of some satisfactory anti-corrosive compositions for ships' bottoms, which have been used successfully for a considerable time by H.M. Navy and on merchant ships. Particulars of their formulation are given on p.204.

The research on the surface preparation of ship plate, mentioned on p.31, has been completed and the results have been presented to, and discussed by, the Institution of Naval Architects and the Institute of Marine Engineers.[6]

In this investigation ship plate in three initial surface conditions, as-rolled, gritblasted, and pickled, was exposed to weathering in a marine atmosphere for periods of up to 12 months. Then the weathered steel was prepared for painting by various finishing treatments, including wire-brushing, gritblasting, and the application of a pretreatment primer. Three different three-coat painting schemes were applied to specimens prepared in this way, after which the painted specimens were immersed for 12 months, both at Caernarvon, by BISRA, and at Emsworth, by the Admiralty. A summary of the most important results is given in Table 1 where each figure is an average of six or more values.

The main conclusion was that the use of a pretreatment primer, which consists of an alcoholic solution of phosphoric acid and polyvinylbutyral resin pigmented with zinc chromate, is materially beneficial to paint performance.

Mr **L. T. Carter** (Admiralty, Bath): The Admiralty has long enjoyed close liaison with the various Corrosion Committees of The Iron and Steel Institute, partly through the medium of the Admiralty Corrosion Committee, which, like the Marine Corrosion Sub-Committee of the Institute, was set up in 1938. Early in the 1939–45 war when the Admiralty wanted research initiated to produce the best performance of underwater paints on ships' hulls, the Marine Corrosion Sub-Committee was asked to collaborate.

Two most important lines of development, dealing with anti-corrosive compositions for the protection of ships' bottoms and the surface preparation of the bottom plating before painting emerged from this work. The first Report of the Sub-Committee, in 1943, also included some research on marine fouling. Although this side of the work was then discontinued, the results were of value, and a notable feature was the development of the leaching rate test, which gives a laboratory method of indicating the probable effectiveness of an anti-fouling composition, and when used in conjunction with raft trials can enable the less promising formulations to be more rapidly eliminated.

Of the most particular value, however, was the work of the Sub-Committee on anti-corrosive compositions, and I should like to refer to this in more detail. This was a systematic research into the formulation of protective paints. By a series of raft immersion trials of 300 or more formulations, first varying the pigment and then the medium as independent variables, a set of promising formulations was evolved from which two, known as 173 and 185, were selected for practical development and have since been widely used on ships' bottoms. The first of these, 173, in a slightly modified form and known as 'Admar', has been the standard protective composition used by the Admiralty for many years. Admar is very little different from the original 173. The raw materials have been defined more closely, e.g. iron oxide to BS Specification instead of Burnt-island red, and importance is given to quality control of the composition to ensure the highest standard of the product and to avoid variations in performance. Admar is now supplied to other government departments to a defence specification, which describes it as a paint suitable for the underwater protection of wood as well as steel. Admar has been used on the weather decks of warships in places where non-slip properties are not required, and we are trying it for machinery bilges, followed by coatings of aluminium paint as a promising solution to the difficult problem of protecting these spaces in ships.

When the Marine Corrosion Sub-Committee was dissolved in 1949, work on anti-corrosive compositions was continued by Joint Technical Panel N/P2, and this has led to the production of Composition no.655 with further improved performance. The Admiralty are now introducing 655 instead of Admar for new construction and in cases where existing ships are cleaned back to bare steel by gritblasting, as we consider that we get the optimum performance from 655 when it is used as part of the best attainable system with our latest improved anti-fouling composition and the best initial surface preparation.

Yet another research into anti-corrosive compositions referred to in this Report is concerned with maintenance painting. This is to meet the need where it exists for a relatively cheap bottom composition which dries very quickly and is of use when the time in dry dock is very limited. Some suitable formulations are being tried out on small naval craft in Royal dockyards. We ourselves, however, have not much demand for such a composition, as both 173 and 655 dry hard overnight and the need for faster drying maintenance materials in an excessively rushed docking seldom arises. Warships normally spend less time steaming than merchant ships and

TABLE 1 Average flaking of paint after 12 months' immersion (% by area)

Initial surface condition	As-rolled			Gritblasted			Pickled		
Weathering period (months)	0	2	12	0	2	12	0	2	12
Finishing treatment									
Wire-brushed	16	8	2	8	2	...	19	2	1
Wire-brushed and pretreatment primer	0	1	1	1	2	...	3	1	1
Gritblasted	8	9	12	...	...	...	...	7	12

more time in harbours where corrosion and fouling conditions are severe. Hence it is important not to depart from the highest standards of application and performance of underwater compositions. If high speed of drying became an overriding consideration, we might prefer an anti-corrosive composition based on chlorinated rubber rather than this type of maintenance composition.

Turning now to surface preparation, the Admiralty has long recognized the prime importance of adequate preparation of the steel surface before painting, particularly for underwater compositions. Millscale is a potent factor leading to corrosion during the early life of a ship and should be thoroughly removed at an early stage. Pickling has for many years been specified for outer bottom plating and other structures particularly liable to corrosion. Gritblasting is now being used by shipyards to an increasing extent, not only for removing millscale but for other applications in construction and maintenance, and as an adjunct to an application of metallized and high-duty coatings. It has certain advantages over acid pickling, and for higher quality steels, such as low-alloy quenched and tempered, gritblasting is definitely preferred. Developments in mechanical methods of gritblasting steel are taking place, and increasing attention is being given to the use of pretreatment primers and surface treatments before painting. For these reasons, the most recent research in the marine corrosion field under the direction of Joint Technical Panel N/P2 is of considerable importance. This comprehensive investigation into the best practical surface preparation for the application of compositions to ships' outer bottoms (A8128*, p.156 of Report) was discussed at a joint meeting of the Institutions of Naval Architects and Marine Engineers earlier this year.[6] The broad conclusions from this work confirm earlier observations that ship bottom compositions may not adhere well to freshly descaled unrusted steel, and paint adhesion may be improved by limited weathering or a suitable chemical surface treatment.

Of special interest in this investigation are the advantages obtained from the use of a pretreatment primer, particularly the improved paint adhesion obtained from the use of a pretreatment primer when paint has to be applied to a gritblasted surface which has not been allowed to weather. This can be of importance when dealing with ships already in service. To reap the full benefits from improved bottom compositions and to make possible a period of up to two years between the dry dockings of ships, we regard it as essential that ships' bottoms which are in a heavily scaled condition, with rust scale overladen with old and badly adhering paint, should be cleaned back to bare steel by some form of gritblasting before these higher performance compositions are applied. When a ship is in service and may have to be dealt with during a normal period in dry dock, there is little possibility of lengthy weathering of the freshly gritblasted surface before putting on the paint, and it is heartening to know from the evidence of these trials that paint adhesion may be improved by the use of a pretreatment primer.

It would have added further to the practical value of this investigation if some account could have been taken of the use of temporary protectives on structural steel in shipyard operations, particularly during new construction. Plating may be kept in the racks for a time before being worked into the ship, and the ship may be a fairly lengthy time on the building slip. There is often a need, therefore, of some form of temporary protective or a primer to prevent extensive rusting before and during fabrication of the hull. Furthermore, gritblasting instead of pickling or weathering is being used increasingly for removing millscale. To get the best value from our paint systems and avoid corrosion, it is important that workmen who carry out the cleaning, preservation, and painting of steel in the shipyard should always recognize that rust on a steel ship is extremely harmful and should be removed before applying preservatives. Despite the conclusion in this Report that a period of weathering of a gritblasted surface can be beneficial to the adhesion of underwater paints, it seems wrong on psychological grounds to allow an immaculate bright surface obtained from gritblasting to rust again. We are told that for plating above the waterline, which is only subject to atmospheric corrosion during its service life, any rusting before painting is detrimental. It is baffling for the shipyard workmen to be told that one part of the hull may be allowed to rust, while another should not. What is the most practicable solution?

It is not very practicable, immediately after gritblasting for millscale removal, to put on a pretreatment primer, followed by the final paint system, before fabrication of the plating into the ship has even started; the plating still has to withstand handling, rolling, marking, transporting, welding, and other shipyard operations during fabrication. On the other hand, if a temporary protective is used it must be easily removable, or alternatively, if allowed to remain on the plating it must be compatible with welding and the paint system subsequently applied, and at the same time give the same benefits to paint adhesion, as a period of weathering or the use of a pretreatment primer. I am not a chemist, but my understanding is that the main function of a pretreatment primer is to improve the adhesion of the paint. The pretreatment primer alone gives only a slight protection against corrosion and is not to be regarded as a substitute for a coat of priming paint. Can we look forward to a pretreatment primer for shipyard use which will combine the functions of a temporary protective and be sufficiently durable in cases where the application of the priming coat of anti-corrosive composition has to be delayed?

The marine corrosion section in the Report summarizes this valuable work with commendable restraint by the statement (p.138): 'The value of correct methods of surface preparation for painting has been demonstrated and several reliable anti-corrosive compositions of reasonable cost have been made available'. It goes on to say that if any further improvement in protection is desired a corresponding improvement in anti-fouling compositions will be necessary. While few anti-fouling compositions remain effective for more than a year, it is equally true that others have been formulated to give a life in service well in excess of this. The effect of a bad surface on a ship's outer bottom may offset the advantage of a good hull form, and the effect of marine fouling can reduce the speed and increase the fuel consumption by substantial amounts. Frequent dockings are therefore necessary to maintain operational speeds, particularly under tropical conditions. The target aimed at by the Admiralty for anti-fouling compositions is complete protection of the hull from fouling for two years under the most adverse fouling conditions. The performance of anti-fouling paints cannot, however, be dissociated from that of the protective composition. It is no good having an anti-fouling of two years' life if it flakes off owing to bad adhesion or failure of the protective coating. Moreover, the mechanism of anti-fouling is delicate and easily upset if the anti-fouling paint is applied over unsuitable substrate. It is important, therefore, that the behaviour of a bottom paint scheme be considered as a whole and related to the service of the ship.

I hope that any further work that takes place on the protective efficiency of ships' bottoms will take some account of the effect of cathodic protection on underwater compositions. The cathodic protection of the outer bottoms of stationary ships, i.e. those laid up or fitting out during building, as well as floating docks and the like, is now common practice, and is

being installed in operational ships on an increasing scale. As a result, there is a need for outer-bottom paints more resistant to alkaline conditions produced by cathodic protection. The conventional type of bottom composition containing oil-based media is saponified by this alkali. It is therefore necessary when ships are fitted with cathodic protection to coat the outer bottom with alkali-resistant paints and also to put on a coating in the region of the anodes, or an alternative such as neoprene sheet stuck to the hull, with a very high electrical resistance to ensure an adequate spread of the cathodic protection currents. The alkali formation occurs at the metal/paint interface, so it is also important to gritblast off all rust, scale, and old paint coatings, before applying the alkali-resistant paint system. Trials suggest that the underwater paints most resistant to normal cathodic protection potentials are those based on vinyl, chlorinated rubber, and epoxy resins, but it is important that whatever paint is used an adequate thickness should be applied. Vinyls were considered the best system for use with impressed-current cathodic protection. They are, however, difficult to apply in sufficient thickness, many coatings being required, and they are also sensitive to moisture on the surface or in the atmosphere during application.

Finally, I suggest that the after end of ships' hulls is a region where some special effort in the fight against underwater corrosion might prove rewarding. There are frequent cases of severe corrosion and erosion of the leading edges of rudders and propeller-shaft brackets. In this area the turbulence of the propeller race tends to tear off the paint, and galvanic action between the propeller and the steel hull often leads to intense localized pitting. Cathodic protection or the fitting of local sacrificial anodes, say of high-purity zinc or zinc–aluminium alloy, help to a certain extent, but it is important to arrange for the correct current density because the deposits of calcium and magnesium carbonates precipitated on the cathodically protected surface tend to be washed away by the screw race and a greater current is needed. We have also found that coatings on the shaft brackets and rudders of neoprene-based paints and high-build materials based on solventless epoxy resins are proving reasonably effective in preventing pitting in this area.

Dr J. Montgomerie, Chief Ship Surveyor of Lloyd's Register, summed up the marine corrosion problem some 25 years ago when he said that 'provided the surface of the steel is clean and provided the paint adheres to the steel there is no problem of corrosion such as we know it today'. The work summarized in this valuable Report makes considerable progress towards this ideal.

Dr **T. A. Banfield** (British Paints Ltd): The work of the Marine Corrosion Sub-Committee and Joint Technical Panel N/P2 has led to the formulation of anti-corrosive compositions, which I prefer to call priming compositions, for ships' bottoms, and which set a standard of performance that paint manufacturers should attain or surpass.

The effect of surface preparation has been emphasized, and just as the BISRA work has led to the formulation of standards for the paints used, I suggest that there is a need to formulate standards for surface preparation. A booklet published by the Swedish Corrosion Committee gives coloured photographs showing the standards of preparation of structural steelwork by different methods of cleaning, hand-cleaning, mechanical wire-brushing, gritblasting.[8] From my own experience in shipyards I feel that there is a real need for pictorial standards of that sort which can be presented to a painting contractor with the instruction, 'This is the sort of surface that we want'. From experience, I contend that it is no use saying, 'We want this gritblasted'. Gritblasting can mean anything from a quick pass with a gritblasting hose to a thorough cleaning, and there is a world of difference in the result.

With regard to film thickness, we have heard from Dr Jordan about what the Americans often call multi-mil coatings, and the use of 100% solids or solventless coatings. Many of these are two-pack, three-pack, and even sometimes four-pack materials which have to be mixed at the time of use. One problem, again from practical experience, is that it is not sufficient to have clear instructions for use on the containers. Someone who really understands what is happening and can train the users must supervise the work. One material which we supplied not long ago consisted of a two-pack material which had to be mixed and applied to the surface, to be followed after 24 h by a curing agent. The users complained that in spite of following the directions on the containers, the result was unsatisfactory. Investigation showed that they had taken the three components, mixed them together and obtained an unmanageable gel that could not be applied. I read the instructions on the containers again and found them perfectly clear. A great deal depends on the class of labour who apply the coatings and on the supervision.

Dr Jordan mentioned that thick coatings are expensive. It follows that because these coatings are applied thickly their spreading rate is correspondingly low. For instance, with an average paint coating of $1\frac{1}{2}$–2 mils dry-film thickness, its spreading rate might be about 600 ft²/gal. If, however, a solventless coating at a thickness of 20 mils is to be applied, its spreading rate will be about 100 ft²/gal. In consequence, about six times as many gallons of paint will be needed to cover a given area, which increases the cost and frequently dismays a potential customer. This is a practical point which cannot be ignored; it is a very real obstacle to the adoption of thick coatings.

Mr **H. Capper** (British and Commonwealth Shipping Co. Ltd): I should like to refer to the service trials which were carried out on the ships of one of the lines in our group, the Union-Castle Mail Steamship Company. As I have only been associated with the company for quite a short time, I cannot comment at first hand on the results in the early stages, but I have seen the ships more recently. By now they have been coated with all kinds of compositions on top of the original trial systems and I can only hope that Dr Hudson obtained as much information as he wanted in the short time in which the original compositions were not painted over. It is always very difficult in a service of this sort to keep one composition throughout when ships are going to different ports and may receive the paint available at the time.

I had a look for the patch on the *Bloemfontein Castle* which was treated with the phosphoric acid wash, and there was no sign of it being any better than the rest. It has probably had about 10 coats of various compositions since it was originally treated.

At present, we are pickling the underwater plates and then using wash primer and a three-coat system of BISRA 655 followed by anti-corrosive and anti-fouling. Recently we had two such ships commissioned which have now been in service for about one year, and we find that considerable rusting is taking place. We think that this is initial rusting, and that as an even greater film thickness of paint is built up it will disappear. It occurred to me after reading the Report, that the length of time of weathering after pickling might be a factor affecting the onset of rusting after painting.

In the case of one of the ships, the plates were pickled by the hydrochloric acid process. This ship took about one year to build, and weathering of the pickled plates would take place during this time. A considerable rust film was found as a result, which in some areas was difficult to remove by wire-brushing. As much as possible was removed and the wash primer put on, followed by the rest of the system before launching. In the case of the other ship, the sulphuric acid process was used; it was weathered for about six months and a similar system applied. Of these two ships, after one year's service, most rust was found on the ship for which the hydrochloric acid process had been used and which had the longer time of weathering. Has Dr Hudson any explanation for this behaviour?

We are continuing to watch these ships, and no doubt in a couple of years' time we may have some settling down and

reduction of rusting as the thickness of paint is increased by subsequent applications. We are tending now to turn to cathodic protection for new and older ships, hoping to save much of the cost of painting.

Dr **Hoar:** Can Dr Hudson expand a little on some of the media used in marine paints? Is chlorinated rubber better than the modified phenolic/linseed/tung vehicle used in a/c no.655 (p.204) or is there nothing to choose between them; and in general how should a paint for resisting salt water be formulated?

Mr **J. T. Crennell** (Admiralty, Portsmouth): I should like to make one criticism and to underline a difficulty in this sort of testing. Most of the tests on marine corrosion or tests of paints, protective methods, or pretreatments are necessarily made on small panels, which are commonly fully immersed and hung from a raft. This may help to place systems in a certain order of preference, but has the grave shortcoming that it cuts out much of the corrosive atmosphere or influences that exist on large structures, which will divide themselves up into anodic and cathodic areas such as cannot exist on a small panel. It is very important that the difference between the large practical structure and the small test panel should not be forgotten.

This applies also to patch tests on hulls, whether of paints or preparations. I think that we have to be very careful not to be misled by single or few tests on specially prepared patches on hulls. The Chairman will be familiar with cases where, for example, gritblasting on a particular section of a hull has apparently given the worst result: it has rusted more rapidly than the remainder of the hull which has not been so treated. That is, however, a completely misleading impression, and it leads to my other point which has to do with paint thickness. When comparing, for example, an as-rolled or pickled surface with a gritblasted surface, it is not fair to put on a single coat of paint, or perhaps even two coats, and make a direct comparison. The gritblasting itself will raise the profile two or three thousandths, and until one has put on one thick or two thin coats of paint there is nothing at all on the peaks of those little alps that have been produced.

Mr **Dolan:** Loss rates determined on small test panels immersed in sea water may be misleading as a basis for design corrosion allowance on structures in tidal conditions, such as jetty piles. As shown by Humble,[7] the surfaces which are exposed to the air between tides become cathodic to the continually immersed surfaces; when the tide is high, the tidal region receives protective current at the expense of the surfaces below low tide. It follows that if a good insulating coating can be maintained in the tidal zone, then less current will flow and the rate of loss below low tide will be reduced; but barnacles and other marine growths tend to destroy soft coatings. May I ask Dr Hudson what effect a continuous layer of barnacles has on the rate of corrosion of steel?

Mr Carter expressed interest in temporary protectives which do not interfere with welding. We are using a varnish of methacrylate resin dissolved in a chlorinated hydrocarbon, which gives protection for a few months. The resin has a low temperature of vaporization and flashes off in advance of the welding arc.

Mr **W. Barr,** O.B.E. (President, ISI): The work of the Corrosion Committee has demonstrated convincingly the importance of surface preparation, with particular reference to the removal of millscale from the steel before painting. Having spent many hours discussing corrosion problems with shipbuilders, I can speak very feelingly on this subject; on many occasions it was difficult to convince our customers that the corrosion troubles experienced in certain ships were due to the presence of millscale.

Of the methods used for the removal of millscale, gritblasting is now the most favoured, but the standard of the surface obtained, which will depend on the type of grit used, is an important factor in relation to the thickness of the paint film subsequently applied.

Another factor which may influence the cost of the gritblasting operation is the type of scale. In certain cases it appears to be much easier to remove the scale from a plate in the as-rolled condition than after normalizing. It should be borne in mind that with the present demand for improved notch ductility, the practice of normalizing is not unusual for certain grades of ship plates.

It is encouraging to note that the advantage of surface preparation of the steel before painting is now widely appreciated in shipbuilding and in structural engineering generally, and this raises a point on which I would appreciate Dr Hudson's advice. Is it better to remove the millscale at the steelworks before despatch, or should this be done in the fabricating shops immediately before painting? If the operation is carried out at the steelworks, the question of surface protection to avoid rusting arises, particularly in plates for the export market.

If temporary surface protection is really necessary, it would appear that a simple application of linseed oil would meet the bill. Is this, however, really worth the cost, since the rust which would inevitably form in transit from the steelworks could be removed easily by wire-brushing immediately before painting?

In conclusion may I raise the serious problem of corrosion in oil tankers, a problem not mentioned in the Report. Did the Corrosion Committee examine this problem?

Mr **Turner:** Dr Hudson did not stress that the main Committee was concerned primarily with preventing corrosion of steels and that the interest in paints was subsidiary. Thus it seems that the classic, extensive, and expensive research on no less than 60 compositions of specially made low-alloy steels has almost been lost in this Report covering 20 years; research shows that some of these compositions of low-alloy steels might be used to reduce loss by corrosion in marine and atmospheric conditions even if by a relatively small amount.

Regarding the Committee's work on anti-corrosive and anti-fouling paints it is well to recall that when that work was started anti-fouling paints had achieved a new and heightened importance. They became scarce when they were most needed and when improved qualities were being asked for by all owners of ships. Especially was that so in places such as Alexandria, where Lord Cunningham's fleet was based in the historic days of Taranto and Matapan, and when fouled hulls could prejudice sea battles and the fate of convoys.

Such circumstances put great emphasis on the Committee's work and it is worth looking at the names of its members as listed in the report. It was aided by four knights, five Lloyd's Register surveyors, six professors, eight Fellows of the Royal Society, and nine experts from the Admiralty. With Dr W. H. Hatfield as its Chairman, Dr G. D. Bengough, Dr S. F. Dorey, Dr U. R. Evans, and Dr J. E. Harris, all of whom became Fellows of the Royal Society, it was an exceptionally good team.

I should like to ask Dr Hudson what has happened to wet-sandblasting. We were shown films of it being used by the Americans on ships in their dockyards towards the end of the war. In the discussion so far we have only heard of pickling and gritblasting. Is wet-sandblasting no longer to be recommended?

Looking now to the future we must note that, just as modern motorcars are using ever thinner steel sheets, so thinner steel plates are being built into ships. Designers use mathematics to calculate how they can reduce weight and this results in a greater surface area exposed to corrosion per ton weight of the ships. The unfortunate fact that some contemporary motorcars have corroded right through from the back of their steel sheets, within a few months of being manufactured, should be a warning. From the outside it was observed that the paintwork was discolouring and on investigation it was found that the steel sheet below the paint had corroded away entirely because water and dirt had lodged on

some inadequately protected ledge or in some inaccessible corner.

Similarly with modern lightweight ships a greater seriousness of corrosion, because of the plates being thinner, must be anticipated. From the corrosionist's viewpoint there is a new aspect to the problem of marine corrosion in the admixture of alloys of aluminium for the upperworks with the steel of the hulls.

Although this is not mentioned in the Report, the expert advice of the Committee was successfully applied to the practical prevention of marine boiler corrosion.

Dr **Wormwell:** The Joint Technical Panel N/P2 which is concerned with anti-corrosion compositions will be meeting very shortly to consider its further programme, and we have in mind such topics as the most suitable paints for use in connexion with cathodic protection.

I should like to emphasize what Dr Hudson has said in the Report in acknowledgments to various people. The N/P2 Panel owes a great deal to Mr F. Fancutt for his leadership over many years and to the valuable co-operation of the Admiralty, the British Shipbuilding Research Association, and the manufacturers of ships' compositions. It is only because of the contributions that each of these was able to make, not only in advice but in actually providing manpower to do the work, that the work has been brought to the present stage.

Dr **Hudson,** in reply: I know that the Committee is in full sympathy with Mr Carter's request for further work on temporary protectives for steel plate. I should also like to endorse Dr Banfield's remarks regarding the value of pictorial standards of surface preparation. These will prove most useful for control purposes, and the Swedish Corrosion Committee is to be congratulated on producing such an excellent set of photographs.[8]

I am interested to learn of Mr Capper's experience of the bottom painting of some liners of the Union Castle fleet, on which we were kindly allowed to make trials. I fully appreciate his difficulty in keeping in touch with these. One of the earliest trials made by the Committee was on the hull of H.M.S. *Bassett*. We followed the preparation and painting of each individual plate in great detail, only to find that by the time of the first inspection in service the topsides had already been painted down to the waterline about half a dozen times by the crew.

Mr Capper enquired about the merits of different pickling processes as a surface preparation for painting. Under laboratory conditions, where the final washing to remove all traces of acid can be carried out efficiently, all the common pickling processes may be regarded as equivalent, whatever the acid used. This was shown conclusively by Fancutt in a research conducted on behalf of the Protective Coatings (Corrosion) Sub-Committee (A 8005, p.150 of Report). However, these ideal conditions do not invariably obtain in industry, and there is something to be said for using the method recommended by Footner. In this the millscale is removed by immersion in hot dilute sulphuric acid, but, after washing in hot water, a final rinse is given in hot dilute phosphoric acid. This leads to the formation of a slight phosphate film on the surface which has some protective value. Moreover, the priming coat of paint can be applied as soon as the steel is dry, while it is still above room temperature. I think that the most probable cause of the difference in the behaviour of the paint on the two ships mentioned by Mr Capper was the greater duration of weathering of the plates of the first one rather than the difference in the acid used in the pickling baths.

Dr Hoar asked what type of medium should be used for underwater structures. Under such conditions, as has been pointed out by Dechaux,[9] anodic and cathodic areas develop locally as soon as any corrosion of the steel takes place, so that the paint film is subjected both to acid and to alkaline conditions. The practical consequence is that the paint medium should be as chemically inert as possible. Good alkali resistance is particularly important when, as Mr Carter mentioned, cathodic protection is used for the hull. In this respect a chlorinated rubber medium, and presumably vinyl, polystyrene, and epoxide resin media, of which I have no direct experience in this field, are greatly superior to the modified phenolformaldehyde/stand oil medium that we used for many of our own compositions. Nevertheless experience has shown that this last medium yields good practical results. It is cheap and gives rise to no difficulty in application. However, we obtained even better experimental results with a chlorinated rubber medium, and such media must have been improved considerably since then. Now that cathodic protection is being used to an increasing extent for hulls, the modified phenolformaldehyde/stand oil medium may no longer prove good enough. If so, chlorinated rubber or another of the media that I have mentioned could be used in its stead.

I agree with Mr Crennell and with Mr Dolan that there are considerable differences between the results of small-scale field tests and practical behaviour in service, so that caution is needed in interpreting the former. Indeed, I have already referred to this point when replying to the discussion at the second session.

Mr Dolan asked for my views on the effects of barnacles. On the whole, fouling organisms seem to shield a steel surface so long as they adhere to it. They often cause trouble when they become detached, through removing the paint film with them, and thus exposing bare steel. I understand that the US authorities who are conducting tests in the Panama Canal Zone have concluded that in some circumstances the copious fouling that forms in these hot equatorial waters actually protects the steel.

Mr Barr referred to temporary protection by means of linseed oil. In our experiments this gave good results provided that the oil film was not too thick. It should be rubbed on or applied from solution at a rate of 1000–2000 ft²/gal. This practice was followed long before we advocated it by the German State Railways for any steelwork that had to be left unpainted overnight after it had been cleaned down. Although thicker films of linseed oil might impair the adhesion of the subsequent priming paint, I think it improbable that the thin films recommended would do so, particularly if a conventional linseed-oil priming paint were used.

I agree with Mr Barr about gritblasting. My personal opinion from visits to shipyards and steelworks is that this is a much cleaner and better process than pickling. The more general adoption of gritblasting would enable the process to be mechanized to a considerable degree and reduce its cost. On the whole, if the steelworks would accept the resposibility, I feel that it would be more practicable to carry out the gritblasting process there.

Mr Turner enquired about wet-sandblasting. I understand that this process has not found favour in UK yards, partly because it leads to the accumulation of large quantities of sand at the bottom of the dock, and also because our medical officers are not satisfied that there is no hazard to the workmen from silicosis. I believe the Chairman can confirm this.

The **Chairman:** Yes, you have put the position very precisely. There is one other disadvantage. Wet-sandblasting leaves a wet surface as compared with dry shotblasting.

WRITTEN CONTRIBUTIONS

Mr **H. Twyford** (W. & J. Leigh Ltd): The contributions of the President and Mr Carter during Session III raised the subject of the protection of shotblasted steel plate during the period between shotblasting and the final painting. The need for some suitable priming or other treatment to prevent corrosion of the metal during this period was expressed, and it was indicated that so far as was known no suitable material or treatment had yet been found.

Since research has been continuing over recent years to find the answer to this problem and a material has been developed which we believe meets the conditions required, a statement of the position might be of interest.

The research work and assessment of results can be divided into two stages.

Stage 1 Work was undertaken initially in our laboratories and then under practical conditions to examine:

(i) the relative performance of paints applied to steel surfaces prepared (*a*) by shotblasting, (*b*) by flame cleaning, (*c*) by mechanical cleaning, and (*d*) by hand cleaning

(ii) the advisability and advantage of protecting a shot-or gritblasted surface during the time before final painting as against allowing the surface to weather unprotected during this period.

This work established that:

(i) shot-or gritblasting gave much better results than any of the other methods

(ii) removal of scale by shot- or gritblasting, controlled both for size of grit and speed of operation, gave an excellent surface upon which to paint subsequently

(iii) shotblasting of the metal before construction and protection of the shotblasted metal during the period of construction was most advantageous.

Stage 2 Having established that a treatment or protective coating was required to protect shotblasted metal during fabrication, the research was then directed to find a suitable treatment or coating to fulfil the following requirements:

(i) rapid drying to permit handling of the plate within 5 min

(ii) no effect upon weld efficiency, and freedom from health hazard under standard ventilation conditions

(iii) provision of a satisfactory basis for subsequent paint coatings of all kinds, i.e. oil-based, alkyd, epoxy, vinyl, chlorinated rubber, etc.

(iv) complete protection for several months.

The research covered comparison under laboratory tests and practical conditions of exposure of the following: (*a*) chemical inhibitors, (*b*) film-forming rust preventatives, (*c*) linseed oil, (*d*) zinc-rich primer, and (*e*) several alternative types of primer.

The results showed:

(i) that the chemical inhibitors and the majority of the film-forming rust preventatives only provided protection for about one month

(ii) linseed oil, while providing a reasonable degree of protection, did not comply with the requirements listed above. When applied at an adequate film thickness it did not dry sufficiently quickly to permit handling and stacking, nor would it provide a sound foundation for some of the paint systems which would have to be applied over it

(iii) the zinc-rich primers tested showed good drying and protective properties, but difficulties were experienced because of a tendency for subsequent coats to blister

(iv) while several of the primers gave satisfactory protection, none was sufficiently quick drying.

From the work carried out only one treatment was found to give successful results and meet the four requirements judged necessary for practical use. This coating has been found to be outstanding and work has been proceeding in the laboratory and under practical conditions, including shipyard conditions, over the last 12 months.

Throughout the processes of rolling, marking-out, cutting, forming, and welding, it has been established that the coating does not in any way interfere with production, and having been subjected to these processes the coating still protects the metal from corrosion.

In one practical trial shotblasted plates and shotblasted coated plates were built into adjacent sections of a vessel under construction. After three months on the stocks the unprotected shotblasted plates had rusted quite severely and there had been some formation of rust scale. Before overall painting could be undertaken, extensive wire-brushing had to be carried out and the rust scale detached by chipping. This proved to be quite a lengthy and costly process, and even then the surface obtained was less sound than that on the adjacent coated plates. The protective coating had stood up excellently over the same period, and the only preparation necessary was a light solvent wash to remove grease and oil which had been deposited on the plate during fabrication, and the cleaning down of the relatively small areas of damage and weld lines. The saving in preparation costs was considerable. After such preparation, the protected plates were coated with a standard bottom treatment before launching. Fitting-out took 4½ months, during which time the ship lay in a fitting-out berth in tidal dock water. Upon examination after dry-docking, no breakdown had occurred.

Having adopted shotblasting as a means of obviating subsequent difficulties attributable to millscale, it is clear that the use of this special coating, applied immediately after blasting, provides a cleaner and sounder surface for subsequent painting at, we believe, no increase in overall cost.

Mr **D. B. Orr** (CIBA (A.R.L.) Ltd): Three closely related aspects of ships' plate protection have been mentioned under separate subjects. They are the use of what have been described as 'the more exotic paints and coatings'; the gritblasting or wheel-abrading of ships' plate before erection; and the corrosion of oil cargo tanks.

'The more exotic paints' clearly refers, among others, to epoxy paints and coatings. They owe their advantage to the twin properties of good chemical resistance and exceptionally good adhesion to metal and to other inorganic surfaces, e.g. rust. That the effectiveness of a coating protection is closely allied to its degree of adhesion is a recognized fact.[10]

If the ship owner is going to pay for the extra cost of such an improved coating, he is entitled to look for protection over a much longer period, three to five times as long as the more conventional paints. It therefore follows that this benefit can only be attained if the coating is put on to a parent metal surface or to oxide film which is firmly adhering to the metal.

Cleaning of ships' plates before building has as its objective the prime object of removing millscale, and thereafter with good wire-brushing the paint films have protected about as well as could be expected of them. Following on that assumption, the argument that the most economic place to clean them, whether chemically or mechanically, is at the steelworks remains perfectly true. If, however, one of the aforementioned expensive coatings has to be applied then the plate ought to be cleaned again and almost certainly by gritblasting.

This consideration is especially relevant in the protection of oil cargo tanks. In this case only a really good coating can be effective, and probably most work has been concentrated on the epoxies. Furthermore, there can be no doubt in this application that they will fail entirely in their function if they do not protect for five years or more. In the case of the oil cargo tank, the problem may be increased by water testing which leaves not only additional rusting, but, from personal experience, adhering mud from an industrial river. I was in the company of Dr Banfield when he measured quite easily 0·010 in. of rust/mud on an oil tank bulkhead after wire-brushing mechanically.

To sum up, if the new and improved coatings or paints based on synthetic plastic materials are to play their full part in preventing marine corrosion, then the plates must be cleaned *in situ* after erection and just before application. A previous cleaning of millscale may make the site gritblasting easier but the double operation might be quite uneconomical. My conclusion therefore contradicts the otherwise perfectly logical suggestion of Mr Barr, which was endorsed by Dr Hudson.

Mr **V. E. Stanbridge** (W. S. Atkins and Partners): I regret that I was unable to participate in the discussions which took place on atmospheric corrosion of bare metals and protective measures, as most of my comments relate not so much to the material of the Report as to the points made in the subsequent discussion.

I suppose I may be considered as one of those civil engineers referred to by Dr Hudson when he said he had been trying for 20 years to teach us the principles of corrosion. If in fact we

appear not to have learnt anything as a result of his efforts then I feel I should reassure him and explain that although we do appreciate the work which he has done we are not always able to take advantage of the results of his investigations because we are precluded from doing so by particular overriding factors. There is an essential difference between the work of the scientist and that of the engineer: the scientist is responsible for investigating and recording scientific facts, whereas the engineer's responsibility is to his client and this almost invariably means the provision of the most financially advantageous solution to his problems. It is here that the engineer's problems arise because the answer which is economically and financially the most advantageous is not always the best.

For instance, we fully appreciate that the preliminary cleaning of structural steel is of vital importance and that the elimination of millscale and rust before the application of the protective coatings is essential if an optimum life from the coatings is to be obtained. However, as Dr Hudson pointed out, the only really satisfactory way of achieving this cleaning is either by phosphating or shotblasting. In the case of phosphating, the size of bath available imposes a limit on the size of the section which can be treated and, for structural purposes at any rate, is impracticable, and shotblasting is expensive. In fact, with our present fiscal system whereby it is possible to obtain tax relief for maintenance costs, it can be shown that unless maintenance work interferes with production it is economically more advantageous to adopt an inferior protective system in the first place and carry out maintenance work at shorter intervals, than to adopt an ideal system initially and reduce maintenance to a minimum. It must be remembered that the greater cost of the initial system implies a larger capital investment with its attendant interest and amortization costs. The engineer, therefore, has to deal with his corrosion problem on an economic rather than scientific basis. Nevertheless it is true to say that the work of the Corrosion Committee has benefited the engineer by providing a sound fund of information on which to base his recommendations to his client.

Perhaps this difference of responsibility can be demonstrated by Dr Jordan's remarks. He confidently asserted that Long's formula for a good thick coat was the answer to almost all of our protection problems, even when applied over rust and millscale. As a scientist he can do this because he is not responsible to a client. As an engineer I should want a lot of convincing that at whatever thickness this could be applied it would be able to resist the forces which are capable of prising the concrete cover from structural steelwork. Something like these forces can be generated when steelwork rusts beneath a paint film. As an engineer I would not be prepared to risk my client's money on the use of this formula without knowing a lot more from practical experience about its potentialities.

May I make one other point? Dr Hoar asked for an extension of the work of the Committee to include an investigation into the behaviour of complete painting systems, including undercoats and finishing coats, and Mr Wilshaw asked for an extension of the Committee's work to include an investigation into the particular application of painting techniques to the products in which he was especially interested. To rush into extensive investigations of this type might well produce a mass of results which it was impossible to correlate and which would, therefore, be valueless. I agree that the scope of the activities of the Corrosion Committee might well be extended but I feel we should be cautious as to the line these extensions should take.

Finally, may I express my own appreciation of the work which the Committee has carried out and the reports which have been published to date. They have proved of very great value to a large number of engineers. Although at times they may not appear to have profited by the results, this is largely due to circumstances outside their control.

Mr **F. C. Porter** (ADA): The references to sprayed metal coatings in the Report are few in relation to the importance of this method of protection: it is appreciated, however, that it is difficult to discuss at length tests which are still in progress and in which many panels show no deterioration after a considerable time.

The Report shows linear corrosion rates with time, of bare steels and of the coating metals, zinc, cadmium, and aluminium. While this is reasonable for steel, and for zinc and cadmium coatings, there is no evidence that it is true for alumnium coatings. In Fig.7, (p.25), for example, the plotted points do not justify a straight line: a curve, turning to run nearly parallel with the Life of coating axis is more in keeping with other experimental observations of long life for aluminium coatings of moderate thickness.

Moreover, I believe that 'failure' in these tests is assessed when the significant surface shows 5% rust. Choice of a greater percentage of rusting as the criterion of failure, as would be realistic for many engineering applications, would be expected by the same reasoning to show the advantage of aluminium coatings to a still greater degree.

The fact that the rate of corrosion of aluminium and its alloys decreases with time is particularly well shown by the results of the ASTM 20-year tests[11] where solid zinc has a linear corrosion/time curve unlike solid aluminium. The uniform dissolution of zinc results in excellent protection to the basis steel during this period but when the zinc has been dissolved the change from 0% to 100% rust will rapidly occur. With aluminium, however, the combined physical and cathodic protection prevents this stage from being readily reached in normal atmospheres. The slight rust-staining which may be experienced in the early days of exposure does not mark at all the onset of breakdown, but only affects the appearance. If this is considered undesirable, it can be avoided by painting the aluminium sprayed coating, but painting is not essential where only structural durability is required. Dr Hudson in a valuable comment on his own tests (p.17) indicates how misleading the external appearance of sprayed aluminium coatings may be as compared with the structural durability which they are providing.

Dr **S. A. Main:** The best information of which I am aware regarding Mr Dolan's question as to the influence of barnacles on marine corrosion can be found in the 18th Report of the Sea Action Committee of the Institution of Civil Engineers.

The committee's extensive exposure trials of bare irons and steels over 15 years in different climates included a variety of conditions under which deposition of shelly fauna occurred, with their seasonal changes.

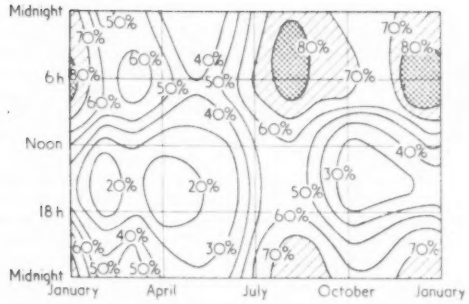
The report which is an assessment by Dr J. Newton Friend, of all factors operating in the research, should be consulted for details on this particular question, but its principal conclusions may be expressed as follows: a compact and adherent deposit, while it lasts, materially retards corrosion of bare steel and iron; sporadic deposits stimulate pitting but have no particular influence on general corrosion.

Information from other and unpublished sources confirms, that, as mentioned by Dr Hudson, on painted steels the local detachment of a deposit, if taking with it the paint, can cause serious pitting there.

Dr Hudson's written reply

I have read and studied the typescript of the verbal discussion and the written contributions with much interest. Many of the points made are in amplification or explanation of observations recorded in the Report, or in reply to comments by other contributors. It seems unnecessary to add anything in these cases, save to thank the persons concerned for their constructive remarks. I propose to confine myself here to answering questions with which I was unable to deal during the verbal discussion, and to extending the replies that I made then when this seems desirable.

Session I As Dr Vernon remarks, it is important to distinguish between soluble and insoluble constituents of the corrosion products; we shall bear this point particularly in mind in our research on the properties of rust. We hope to include a



E *Annual variation in relative humidity at New Delhi*

study of the effects of different types of atmospheric pollution on the rates of rusting and the composition of the rusts. This may enable us to establish the separate and joint effects of sulphate and chloride pollution, to which Dr Vernon refers.

Mr Evans questions whether there is an advantage from the corrosion point of view in using low-alloy steels. I think that they will prove potentially useful under most conditions of outdoor exposure. There is no doubt of their superiority over ordinary mild steel in cases where the protective coating cannot be readily renewed, as in that of the coal wagons mentioned by Mr Turner.

The meteorological data for Delhi to which I referred in my verbal reply have now been received. A diagram of the relative humidity is shown in Fig.*E*. This confirms the statement that I made at the meeting to the effect that the relative humidity at Delhi is generally low.

I also referred then to the fact that the average annual relative atmospheric humidity was less at New York than at London. This seems to be true for the USA generally as compared with the UK. Indeed, the effect of humidity in determining rusting is well brought out by comparison of the two diagrams shown in Fig.*F*; (*a*) is a 'corrosion map' of the United States;* (*b*) shows the average annual rainfall, which may be assumed to bear a rough relationship to the average relative humidity.

* This map was published anonymously in *Plating* about a year ago. It is based on the observed or estimated time of exposure needed to 'corrode a 28–G (US, i.e. 0·0126 in.) steel sheet to a severe degree'. I have simplified the map by reducing the number of divisions to four.

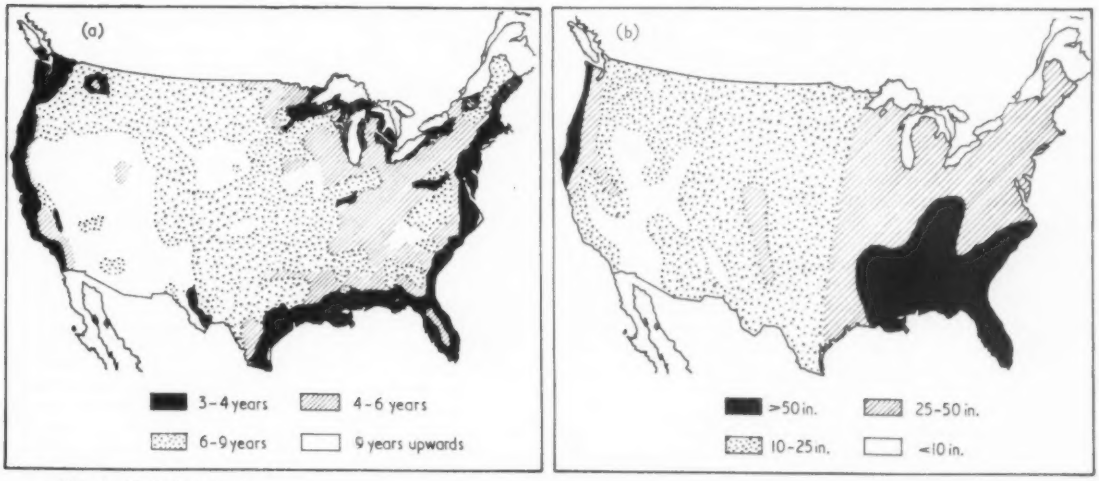
Session II My verbal reply to Dr Jordan's stimulating remarks needs a little extension. We do not know as yet whether it is better to use sprayed aluminium or sprayed zinc to protect steel. Much depends upon the service conditions to which the sprayed steel is exposed, and each metal appears to have its own fields of usefulness. Nor is the painting of these sprayed coatings, in which Mr Dolan also expressed an interest, fully understood. My present opinion coincides with Dr Jordan's, namely that the first essential is to fill the pores (define these how one will) in the sprayed metal surface; we may have different opinions on how this should be done. Further light may be thrown on the subject by a sponsored series of trials of painting schemes for sprayed metal coatings that will be undertaken shortly by BISRA's Corrosion Advice Bureau. I also agree with Dr Jordan that there is much to be said for paints that can be applied thickly but, as he will certainly appreciate, care must be taken not to secure the increased thickness at the expense of other essential paint properties.

As I said at the meeting, I echo Dr Hoar's desire for increased activity by the Committee, particularly in regard to tests on complete painting schemes as distinct from single priming coats. Yet I think that on reflexion he would wish to withdraw his remark that the Committee's effort has been on a very minor scale compared with that of any fairly large US steel company. To the best of my knowledge, few, if any, American companies have issued 150 or more publications, many containing the results of original work, about the corrosion of iron and steel.

The subject of temporary protective coatings raised by Dr Edeleanu is a wide one. They range from thin films of linseed oil rubbed on to prevent clean steel from rusting overnight before it is painted the following morning, to strong hermetically sealed plastic wrappings, which will last for years. The only answer I can give within the present narrow compass is that good proprietary temporary protectives will generally do what is claimed for them, and that in any particular case it is wise to consult a reputable maker.

My reply to Dr Edeleanu's second question is that the modern coatings, such as those based on epoxide resins, have attractive properties but that in view of the long periods that are needed for exposure trials, since a good oleo-resinous painting scheme of the older type will have a life of well over ten years, it is not yet possible to make final assessments of their merits.

I agree with Mr Mansford that sprayed metal coatings are of value when steelwork has to be left a long time before it is



a life of a 28-G steel sheet
b rainfall

F *Correlation of corrosion and rainfall in the USA*

TABLE 2 UK deliveries of finished steel, 1957

	Total	Heavy steel		Light steel	
	Tons, $\times 10^6$	Tons, $\times 10^6$	Surface area, $ft^2 \times 10^6$	Tons, $\times 10^6$	Surface area, $ft^2 \times 10^6$
Plates	2·9	2·9	1160	...	...
Heavy sections	2·2	2·2	440	...	...
Light sections	3·4	1·1	550	2·3	1150
Hot-rolled strip and tubes	1·5	0·3	270	1·2	1080
Cold-rolled strip and sheets	3·7	...	...	3·7	11100
Wires and wire rod	1·1	0·5	1750	0·6	2100
Rails, forgings, and castings	1·9	1·9	190	...	...
Total	16·7	8·9	4360	7·8	15430

painted. However, I subscribe to the view that, where practicable, it is desirable to paint the metal coating immediately after spraying. Both zinc and aluminium are corrodible, and moreover, sprayed metal coatings retain dirt easily because of their roughness. Consequently, a sprayed metal coating that has been left for any length of time may need cleaning down before it is painted, and I have known cases in which failure of the painting scheme has been caused by the omission to do this.

As Dr Evans remarks, the presence of ferrous sulphate, whether in the rust or the paint pigment, can seriously impair paint performance. We shall pay particular attention to this in our studies of the properties of rust, regarding which we are glad to have the benefit of the advice of Dr J. E. O. Mayne, to whose work Dr Evans has referred.

Dr Jordan may be right in his view that inhibitive pigments are less important in thick films than in thin ones. Much depends on the surface preparation of the steel. What is more certain is that inhibitive pigments are less important when the priming paint is applied to a properly descaled, pickled, or gritblasted surface. In such cases a non-inhibitive priming paint, e.g. micaceous iron ore, has been known to give comparable results to red lead.

One of the difficulties in protecting steel chimneys, about which Mr Dolan asks for guidance, is that some of the best heat-resisting paints have to be stoved. Sometimes the heat of the chimney may be relied on to do this but the paint will be vulnerable to bad weather in the early stages of its life, before the film is fully cured. In laboratory tests, heat-resisting paints containing zinc dust, aluminium powder, and mica in silicone resin or alkyd media have performed well. I understand that certain air-drying paints in a silicone-alkyd medium are on the market and have proved fairly satisfactory in service.

The breakdown of UK steel deliveries that I mentioned in my verbal reply is given in Table 2; the figures relate to the year 1957. Too much importance should not be attached to these data, because I have had to make certain assumptions in the calculations which may be wide of the mark. However, they indicate that the production is approximately equally divided by weight between 'heavy' and 'light' material, but that the area that may stand in need of a protective coating is several times greater for the light products than for the heavy ones.

Session III I am interested to learn from Mr Carter that the Admiralty intend to substitute our a/c no.655 for Admar (a/c no.173). The former contains a proportion of aluminium powder in the pigment instead of white lead, and its medium has been improved by the incorporation of tung oil. It has given better results than a/c no.173 both in raft tests and service trials.

I share Mr Carter's regret that the recommended procedures for the surface preparation of underwater plates and above-water plates, respectively, should differ. The facts are that the development of rust on pickled or gritblasted steel worsens the performance of paint when the painted steel is exposed outdoors, but that, where underwater exposure is concerned, paint often fails to adhere well to freshly descaled surfaces, and adhesion is improved by a moderate degree of rusting, followed by wire-brushing immediately before painting. I agree that psychologically it is unsound to allow bright steel to rust again; in the case of bottom plates, it is possible that in practice little would be lost by applying a pretreatment primer immediately after pickling or gritblasting, instead of after the descaled steel has been weathered for a few weeks, as we recommend.

I do not follow Dr Banfield's point about the expensiveness of thick coatings. The ultimate criterion, if we accept the necessity for a fixed minimum dry-film thickness, is the cost of the dried paint per cubic inch. If so, it is economically advantageous to put on the desired thickness in a single coat instead of several, because of the saving in labour. Admittedly, paints that yield thick coatings may cost more per cubic inch of dry paint than ordinary paints; if so, the additional cost must be balanced against the possible saving in labour costs.

Mr Capper will find detailed information about the effect of the duration of weathering between pickling and painting in the INA paper to which I referred in my verbal reply. Much will depend on the severity and nature of the atmospheric conditions. In general, assuming that the plate is thoroughly wire-brushed before painting, I should expect paint adhesion to be materially improved by weathering for a period of 1–2 months; thereafter the adhesion would not be greatly affected by prolonging the weathering period up to 12 months.

Mr Crennell's point about the unfairness of comparing gritblasted surfaces with smoother surfaces under one or two coats of paint will be generally accepted. In fact it is considered good practice to allow for the roughness of the gritblasted surface by applying an extra coat of paint.

I am glad to learn of Mr Dolan's experience of a temporary protective based on methacrylate resin. This sounds useful and we will try it.

In further reply to Mr Barr, the Committee has made no direct experiments on the corrosion of oil tankers but several inspections of corroded tankers have been made. As he remarks, some types of oxide scale can be removed more readily by gritblasting than others. The removal of millscale can sometimes be facilitated, and the cost of the operation reduced, by allowing the steel to weather for a short time beforehand. However, this may be a dangerous practice, since if serious rusting occurred matters would be made worse.

Written contributions Mr Twyford's contribution is interesting but loses a great deal of its force because he does not tell us what his special coating is. Presumably it will be patented in due course and become yet another proprietary material. If the claims that he makes for it are substantiated in service, it will certainly prove a valuable temporary protective. The results that he obtained in stage 1 of his experiments agree with those of the Committee's work. In particular, although flame-cleaning is a good means of surface preparation it is not so good as gritblasting.

The main point raised by Mr Orr is whether the surface preparation of heavy plates and sections, by gritblasting pickling, or other means, should be carried out at the steelworks or elsewhere. In the course of the verbal discussion, Mr Barr and I suggested that the former was preferable. Mr Orr considers, however, that the plates should be gritblasted *in situ*. I would not quarrel with his opinion for the use he has in mind: oil tankers. Each case has its own special features and must be judged accordingly. The main result of research in this field has been to establish, and gain general acceptance of, the principle that structural steelwork should be descaled before it is painted. There are obvious advantages in centralizing this work so far as possible. Whether the central descaling plant should be at the steelworks, the constructional works, or even, for large structures, at the site, may still be open to question.

Mr Stanbridge's remarks remind me of the old tag 'The Law is an ass'. So is the fiscal system, if tax relief on maintenance costs has the effect that he indicates. In brief, I am one of the old-fashioned types to whom unnecessary waste is abhorrent

and anti-social. Whether tax relief is allowable or not, the best course in the interests of the community is to reduce the overall cost of the initial protection and of maintenance to a minimum, and as a rule this cannot be achieved by skimping the cost of the initial protective scheme.

I doubt whether the number of specimens that we have on test will suffice to enable us to decide with certainty the nature of the corrosion/time curve for aluminium coatings, which Mr Porter suggests is not linear but convex towards the Weight of coating axis. He will concede, I think, that data for solid aluminium are not necessarily applicable to sprayed aluminium coatings on steel. We will bear his remarks in mind when drawing up our next report on this branch of our work.

Dr Main's reference to the work of the Sea Action Committee of the Institution of Civil Engineers on the effects of barnacles is welcome and apt. Their results are in line with those of the Panama Canal authorities to which I referred at the meeting.

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Symposium on steels for reactor pressure circuits

As previously announced, The Iron and Steel Institute has arranged a symposium on 'Steels for reactor pressure circuits' to be held at the Hoare Memorial Hall, Church House, Great Smith Street, London SW1, from Wednesday to Friday, 30 November to 2 December 1960. It will be included in the activities of the British Nuclear Energy Conference, of which the Institute is a member.

Details of the papers to be presented were given on p.91 of the 'News' section of the September *Journal*. Papers are being preprinted and will appear early next year, together with reports of the discussions, in the Institute's *Special Report* series. The volume will be supplied at a price to be announced later.

Preprints, which will be mailed *in two separate groups*, will only be sent to those whose order for a bound volume is received by the Secretary before the meeting.

FORTHCOMING MEETINGS OF THE GROUP

1960 Winter Meeting, 15 and 16 December 1960

The next meeting of the Powder Metallurgy Joint Group will be held at Church House, Great Smith Street, London SW1, on Thursday and Friday, 15 and 16 December 1960. The programme is detailed below.

15 December, Afternoon (2.30–5.0 pm)

Theme: *Sintered stainless steel.* A discussion of the following two papers, published in *Powder Metallurgy*, no.5, 1960, pp.85–115:

'Sintered stainless steel, I—The influence of alloy composition upon compacting and sintering behaviour', *by R. L. Sands and J. F. Watkinson.*

'Sintered stainless steel, II—The properties of stainless steel powders sintered in dissociated ammonia', *by R. L. Sands and J. F. Watkinson.*

Friday, 16 December

Symposium on practical aspects of pressing metal powders, based on a series of papers previously printed in *Powder Metallurgy*. (The paper by Livey *et al.* was printed in no.5, pp.130–48; all the other papers will be published in no.6, due for despatch in November.)

Morning Session (9.30 am–12.30 pm)

Presentation and discussion of the following papers:

'Some developments in metal powder presses', *by J. Oakley* (Manganese Bronze and Brass Co. Ltd, Ipswich)

'The influence of tooling methods on the density distribution in complex metal powder parts', *by H. G. Taylor* (Höganäs-Billesholms AB, Höganäs, Sweden)

'Some fundamental studies in the cold compaction of plastically deforming solids', *by D. Train and J. A. Hersey* (School of Pharmacy, University of London)

'Determination of hoop stresses induced in a cylindrical steel die by compacting metal powders', *by S. J. Bustamante and H. Sheinberg* (Los Alamos Scientific Laboratory, University of California, Los Alamos, USA)

'Radial pressures in powder compaction', *by W. M. Long* (Atomic Weapons Research Establishment, UKAEA, Aldermaston)

'The displacement of gas from powders during compaction', *by W. M. Long and J. R. Alderton* (Atomic Weapons Research Establishment, UKAEA, Aldermaston)

Afternoon Session (2.0–5.0 pm)

Presentation and discussion of the following papers:

'The compacting of metal powders by explosives', *by W. T. Montgomery and H. Thomas* (Imperial Chemical Industries Ltd, Nobel Division, Stevenston)

'Aspects of the volume production of green porous bearing compacts', *by M. A. Pound et al.* (Bound Brook Bearings Ltd, Lichfield)

'The processing of enriched uranium oxide–paraffin wax mixtures', *by L. D. Huckstepp and G. V. Day* (Atomic Weapons Research Establishment, UKAEA, Aldermaston)

'The compacting of graphite and graphite–uranium–thorium mixtures', *by D. T. Livey et al.* (Atomic Energy Research Establishment, UKAEA, Harwell)

'The isostatic pressing, vacuum sintering, and swaging of thorium powder', *by H. Lloyd and A. E. Symonds* (Atomic Energy Research Establishment, UKAEA, Harwell)

'The production of hollow shapes in beryllium powders by various techniques', *by G. C. Ellis* (Atomic Weapons Research Establishment, UKAEA, Aldermaston)

'Hot pressing of ceramic powders', *by A. G. Thomas and H. J. Jones* (The Plessey Co. Ltd, Towcester)

'The manufacture of massive forms of tungsten and molybdenum', *by L. G. Rattray* (Cleveland Wire Plant, General Electric Co., Cleveland, Ohio, USA).

1961 Spring Meeting

The Spring Meeting of the Group will be held at the Royal Commonwealth Society, Northumberland Avenue, London WC2, on Monday and Tuesday, 17 and 18 April 1961, when there will be a discussion on '*The appraisal of powders for pressing and sintering*'. The afternoon of Monday, 17 April, will be devoted to a discussion of three specially invited review papers dealing with '*Techniques for the evaluation of powders*'. The whole of Tuesday, 18 April, will be occupied with a discussion on "*The relationship between properties of powders and their pressing and sintering behaviour*'.

The Powder Metallurgy Joint Committee invites the submission of papers describing original, unpublished work for publication and discussion at this meeting. Offers of such papers, accompanied if possible by brief synopses, should be sent to the Secretary to the Group as early as possible; the last date for the submission of MSS will be 30 November 1960.

1961 Winter Meeting

The principal theme for discussion will be '*Sintered materials for high-temperature service*'.

Offers of papers describing original, unpublished work for this meeting are invited.

1962 Spring Meeting

The principal subject for discussion will be '*Disperse-phase-hardened systems*'.

Offers of papers describing original, unpublished work are invited.

NEWS

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

AUTUMN GENERAL MEETING 1960

As previously announced, the Autumn General Meeting of the Institute will be held at Church House, Great Smith Street, London SW1, on Tuesday and Wednesday, **29 and 30 November 1960,** beginning at 9.30 am.

The proceedings will include a meeting on fluid flow in furnaces and converters (*29 and 30 November*), and a meeting on martensite (*29 November*). Full details of these meetings were given in the July 'News' (p.341).

SYMPOSIUM ON STEELS FOR REACTOR PRESSURE CIRCUITS

The Institute is also arranging a symposium on steels for reactor pressure circuits. This will be held at Church House from Wednesday to Friday, **30 November to 2 December 1960.** Further details are given on p.351 of this issue.

13th Hatfield Memorial Lecture

Mr L. Rotherham, M.SC., F.INST.P., has accepted an invitation to deliver the 13th Hatfield Memorial Lecture. He will take as his subject 'The contribution of metallurgy to electric power generation'. The lecture will be given at the Hoare Memorial Hall, Church House, Great Smith Street, London SW1, at 6.30 pm on Tuesday **29 November 1960.**

Admission will be by ticket only, which may be obtained from the Secretary.

NEWS OF MEMBERS

Master Cutler

Mr C. H. T. Williams (*Vice-President*) was installed as Master of the Company of Cutlers in Hallamshire on 4 October.

Dr **N. P Allen** (*Honorary Member of Council*), is President-elect of The Institution of Metallurgists.

Dr **D. V. Atterton** has been elected a member of council of the Institute of British Foundrymen.

Mr **W. Banks** is now general manager of the Ravenscraig Works of Colvilles Ltd.

Mr **W. Gusworth** has been elected to the board of Brightside Engineering Holdings Ltd and has been appointed managing director of Buckley and Taylor Ltd.

Mr **L. Graham Firth** has been elected deputy chairman of Brightside Engineering Holdings Ltd.

Mr **W. W. Kee** has been appointed managing director of a new company, Alcan Enfield Alloys Ltd.

Dr **J. W. Martin** has been elected a Fellow of St Catherine's College.

Mr **Neil Metcalf** has been appointed assistant general manager of the Burlington Steel Company Ltd, Hamilton, Ontario, Canada.

Mr **James Mitchell** has joined the board of The Patent Shaft Steel Works Ltd.

Mr **F. J. Somers** has been appointed a director of Mitchell, Shackleton and Co. Ltd.

Mr **P. Wright** has been elected to the board of Brightside Engineering Holdings Ltd and has been appointed managing director of the Brightside Foundry and Engineering Co. Ltd.

Mr **A. Young** has been appointed general manager of the Clyde Iron Works and Clydebridge Steel Works of Colvilles Ltd.

OBITUARY

Sir **Charles Bruce-Gardner,** Bt (*Past President, elected 1910*) at his home in Berkshire on 1 October.

AFFILIATED LOCAL SOCIETIES

Sheffield Metallurgical Association
Autumn lecture programme

The Sheffield Metallurgical Association has announced the following lectures, all of which will be given at the BISRA laboratories, Hoyle Street, Sheffield, at 7 pm unless otherwise stated.

15 November 'Some aspects of hydrogen in steel', by J. Hewitt.

22 November 'Some applications of castables and mouldables in the iron and steel industry', by Dr R. W. Grimshaw (7.30 pm)

29 November 'Some aspects of research for steel foundries', by Dr A. H. Sully (Joint meeting with the Sheffield Society of Engineers and Metallurgists)

6 December 'Atomic absorption', by R. Lockyer

8 December 'Electron microscope observation of dislocations in crystals', by Dr P. B. Hirsch (Joint meeting with The Institute of Metals, Sheffield section, Engineering Lecture Theatre, St George's Square, 7.30 pm)

BRITISH STEEL CASTINGS RESEARCH ASSOCIATION

Staff changes

The Council of the British Steel Castings Research Association, Sheffield, announce that following the resignation of the Association's secretary, Mr J. Bolton, who has been appointed director and secretary of the British Steel Founders' Association, the following appointments have been made:

Mr *E. R. Smith*, who has been in charge of the Accounts Department since 1952, has succeeded Mr Bolton as secretary.

Mr *C. M. Stoch*, DIPL.ING., F.I.M., has been appointed assistant director of research. Mr Stoch, who joined the association in 1951, has been in charge of the Plant Engineering and Industrial Health Section since 1953, and for the past two years has also been acting head of the Steelmaking Section.

Mr *K. Knaggs*, B.SC., deputy head of the Association's Steelmaking Section for the past two years, has been appointed head of this section.

Miss *C. M. G. McBroom*, B.A., hitherto private secretary to the director (Dr A. H. Sully) has been appointed technical secretary.

EDUCATION

JOINT COMMITTEE FOR NATIONAL CERTIFICATES AND DIPLOMAS IN METALLURGY

Revised administrative arrangements, 1961 and future years

In recent years, the expansion in the work of the joint Committee for National Certificates in Metallurgy has thrown an increasing financial burden on The Iron and Steel Institute, the Institution of Mining and Metallurgy, The Institute of Metals, and The Institution of Metallurgists. There appeared to be no likelihood of improving this position considerably in the near future. It has therefore been agreed between the constituent bodies and the Ministry of Education that, from January 1961, the Ministry, instead of The Institution of Metallurgists, shall be responsible for providing the office administration of the Joint Committee.

Hitherto the Registrar-Secretary of The Institution of Metallurgists has been the Secretary of the Joint Committee. There will in future be Joint Secretaries: the Registrar-Secretary and an officer of the Ministry of Education. All correspondence arising from the work of the Joint Committee should be addressed to the Joint Secretary at the Ministry of Education.

The constitution, membership, and chairmanship of the Joint Committee will remain unchanged. The four institutes and the Ministry are agreed that it is particularly important that the closeness and effectiveness of their co-operation in the work of the Joint Committee should not in any way be reduced by the new arrangements. To this end the arrangements both for the appointment of assessors by the institutes and for detailed consultation as necessary, between the Ministry and the Registrar-Secretary of The Institution of Metallurgists, between meetings of the Joint Committee will remain unaffected.

The four institutes will continue, as hitherto, to provide funds for the award of prizes on the results of the National Certificate examinations.

Beilby Medal and Prize, 1961

Since 1930, at intervals of one or more years, awards have been made by the Administrators of the Sir George Beilby Memorial Fund, representing the Royal Institute of Chemistry, the Society of Chemical Industry, and The Institute of Metals. Sir George Beilby had been President of each of these three bodies, and they jointly sponsored the appeal for subscriptions whereby the Fund was raised as a memorial to him after his death in 1925.

The awards are made to British investigators in science in recognition of independent original work of exceptional merit, carried out continuously over a period of years and involving the development and application of scientific principles in any field related to the special interests of Sir George Beilby, i.e. in chemical engineering, fuel technology, or metallurgy, in their modern interpretations. The awards are intended as an encouragement to younger men and women (preferably under the age of 40) who have done distinguished work of practical significance in any of these fields.

In 1958 two awards, each of 150 guineas, were made. It was then agreed that no further award would be made before 1960. The administrators have decided that henceforth each award shall consist of a gold medal as well as a substantial sum of money, and shall be known as 'The Beilby Medal and Prize' and specified as being 'For advancement in science and practice'. Such an award will be offered at intervals of two years, but more than one may be made on the same occasion if there are several candidates of sufficiently outstanding merit.

Consideration will be given in due course to the making of an award (or awards) from the

Fund in 1961. Outstanding work of the nature indicated may be brought to the notice of the Administrators, either by persons who desire to recommend the candidate or by the candidate himself, not later than *31 December, 1960*, by letter addressed to *The Convenor of the Administrators, Sir George Beilby Memorial Fund*, The Royal Institute of Chemistry, 30 Russell Square, London WC1.

The letter should be accompanied by *nine copies* of a short statement on the candidate's career (date of birth, education, and experience, degrees and other qualifications, special awards etc., with dates) and of a list of titles, with references, of papers or other works published by the candidate, independently or jointly. Photographic copies of these documents are acceptable. Candidates are also advised to forward one reprint of each published paper of which copies are available.

Th. Kootz

C. Hulse

CONTRIBUTORS TO THE JOURNAL

Th. Kootz, DIR.PROF.DR.—Manager, Research Department August Thyssen-Hütte AG, Duisborg-Hamborn, Germany.

Dr Kootz was born in 1911 in Herrnhut, Saxony. He studied philology for a time at the Leipzig University before joining the Bergakademie, Clausthal, to study ferrous metallurgy. He later continued his studies at the Technical College in Aachen, finally graduating in 1940. He had joined the August Thyssen-Hütte AG two years previously. In 1949 Dr Kootz was appointed Oberingenieur at the Clausthaler Eisenhüttenmännisches Institut. He rejoined August Thyssen-Hütte in 1952. Since 1958 he has also been a lecturer in metallurgy at the Bergadakemie in Clausthal.

C. Hulse, PH.D., B.SC.—Senior Lecturer, Department of Fuel Technology and Chemical Engineering, University of Sheffield.

Clifford Hulse graduated from Birmingham University in 1941 and entered the steel industry as a fuel technologist. He worked at first for the M.A.P. and was later with Hadfields Ltd under Dr R. J. Sarjant. In 1947 Dr Hulse joined the Department of Fuel Technology at Sheffield, of which Dr Sarjant was then professor. Dr Hulse's main fields of interest are aerodynamics, combustion, and heat transfer, but he has also worked on general fuel economy and gas cleaning. He is the present chairman of the Yorkshire Section of the Institute of Fuel.

D. Hardwick, B.MET., PH.D.—Research Metallurgist, Brown Firth Research Laboratories, Sheffield.

Dr Hardwick was born in 1926 and educated at Tadcaster Grammar School and Sheffield University, from which he graduated in 1947. After appointments at the English Electric Company at Stafford, BISRA's Sheffield laboratories, and the BSA Group Research Centre, Dr Hardwick returned to Sheffield University in 1955 as a C. H. Desch Research Fellow, to carry out research on the deformation of metals at high temperatures and strain rates, and in particular into factors affecting hot workability. He took up his present post with the Brown Firth Research Laboratories in 1959.

K. R. Pirt, L.I.M.—Research Metallurgist, Brown Firth Research Laboratories.

D. Hardwick

K. R. Pirt

Mr Pirt was born in Manchester in 1936 and attended High Storrs Grammar School, Sheffield, and later the College of Technology. He gained the H.N.C. in metallurgy in 1957 and was awarded his L.I.M. in 1959. He is at present concerned in research into brittle fracture of alloy steels.

NEWS OF SCIENCE AND INDUSTRY

Obituary

Mr **W. H. A. Robertson,** founder of the firm of W. H. A. Robertson and Co. Ltd, part of the Tube Investment organization, died recently, aged 79. He founded the firm in 1907 in a building 50 ft × 20 ft, with five employees, for the manufacture of rolling mills and metal-working machinery. He retired from active participation in the business in 1954 while remaining a director.

Mr Robertson played an important part in founding The Institute of Metals, of which he was a Fellow and a Life Member.

The death occurred on 20 September of Mr **George Archer,** president of The Mond Nickel Company Ltd. Mr Archer, who was appointed president in July of this year, had been chairman of the company and its subsidiary, Henry Wiggin and Co. Ltd, since July 1959. He joined the board of The Mond Nickel Company in 1948 and became sales director in 1952 and managing director in 1955.

AIMME President for 1961

Mr Ronald R. McNaughton, of Trail, British Columbia, has been elected president of the American Institute of Mining, Metallurgical, and Petroleum Engineers for 1961. He will take office on 28 February, during the Institute's annual meeting at St Louis. Mr McNaughton is manager of the metallurgical division of The Consolidated Mining and Smelting Co. of Canada Ltd.

£32½ m. expansion scheme

Under a new development scheme costing a total of £32½ m., Appleby-Frodingham Steel Company plans to increase its productive capacity for iron and steel and to install a new rod/bar mill, and Samuel Fox and Co. Ltd is to add 100000 tons a year to its steelmaking capacity.

These major projects, which are scheduled for completion by the autumn of 1964, represent the largest development scheme ever to be undertaken by the company. Iron and Steel Board approval has been given. When completed, together with other schemes already in hand, the ingot capacity of United Steel will be raised from its present level of about 3 million tons to about 4 million tons a year.

At present, Appleby-Frodingham has a planned annual productive capacity of slightly exceeding 1 million tons of plates and sections. By the end of 1964, however, with the addition of the output from the rod/bar mill, this figure will approach 1400000 tons of finished products a year.

The decision to install a rod/bar mill with an additional capacity of 300000 tons per annum has been taken to diversify the company's output of finished products and to extract the full potential from the existing primary iron and steelmaking plant at Appleby-Frodingham Scunthorpe works.

South African co-operation

Babcock and Wilcox Ltd and Vanderbijl Engineering Corporation (Vecor) of Pretoria have finalized a long-term agreement with a view to closer co-operation of their manufacturing activities in South Africa. Under the agreement, which will come into force at the end of 1960, the manufacturing facilities of Vecor will be expanded by purchasing works at Vereeniging of Babcock and Wilcox of Africa (Pty).

Skefko in Scotland?

The Skefko Ball Bearing Company Ltd announce that they are considering the formation of a subsidiary company with the main purpose of developing the company's activities in technical and manufacturing research.

The new company would be located near Irvine in Ayrshire, Scotland, where, subject to the satisfactory conclusion of present negotiations, it is intended to construct a factory with facilities for manufacturing production tools, equipment, and some of the specialized machine tools used in the manufacture of ball and roller bearings. It is not, however, the intention of the company to reduce the present toolroom activities at Luton; on the contrary, it is hoped to develop these facilities still further. In addition it is intended to house at Irvine certain auxiliary departments concerned with manufacturing operations which can most conveniently be separated from the main production of bearings at Luton and Sundon.

Creep/rupture testing

Electric furnace zone control to within ½°C or closer has been achieved at a new creep/rupture testing installation at Colvilles Ltd. This is believed to represent finer control of temperature than has been obtained hitherto in this type of work.

The first of six new electric resistance furnaces, which will be used to collect creep/rupture data on various steels produced by Colvilles, is now fully working under control of instrumentation designed to keep the temperature of specimens and furnace zones within very close limits. Each furnace will operate at a different temperature: 400°, 450°, 475°, 500°, 525°, and 550°C, all ±10°C. The temperature control is well within the tolerances laid down by the appropriate British Standards governing this type of test.

Each furnace is itself divided into six zones containing thermocouples; thermocouples are also placed adjacent to the specimens. Using Colvilles' own switchgear panel, measurements of these points are taken in sequence, thermocouples being connected for a few seconds each. A continuous record is given on a Honeywell 'ElectroniK' strip chart recorder-controller; the ink trace is continuous since there is an 'overlap' in the switchgear which provides the average of the temperature of two zones when switching over from one zone to another.

The ElectroniK instrument acts as a controller in conjunction with the switchgear panel and experience with the first furnace shows a maximum variation of ½°C per zone and 1½°C over the whole furnace under the worst combination of errors.

Swedish hot-topping process

G. P. Hinckley and Sons Ltd, Sandiron House, Beauchief, Sheffield 7, have been appointed sole and exclusive agents for the UK and Eire for the 'Tiger-Top' process for hot-topping steel ingots. This is a patented process developed by the Swedish Degerfors Steel Works.

Joint British Committee for Stress Analysis

Following an exploratory meeting on 1 March 1960, arranged by the Institute of Physics, a Joint British Committee for Stress Analysis has been set up in the UK.

This committee will represent UK interests in the field of stress analysis at the periodic meetings of the Permanent Committee which

are held in Europe and will thus ensure adequate British participation in international conferences in the field of stress analysis.

The principal object of the Permanent Committee, membership of which is open to all west European countries, is the furtherance of international collaboration in the field of stress analysis, and in seeking to achieve this end international conferences will be arranged at 4-year intervals. Such conferences will normally be phased with the International Congress on Applied Mechanics. The officials and secretariat of the Permanent Committee will normally be appointed by the National Committee in whose country the next international conference is due to be held.

The objectives of the Joint British Committee for Stress Analysis will be to act in the collective interest of the constituent bodies: (*a*) by maintaining liaison with the Permanent Committee for European or international conferences on stress analysis, and (*b*) by maintaining liaison with overseas societies and institutions concerned with stress analysis.

The Joint British Committee consists of representatives appointed by The Royal Aeronautical Society, The Institution of Civil Engineers, The Institution of Electrical Engineers, The Institute of Marine Engineers, The Institution of Mechanical Engineers, The Royal Institution of Naval Architects, The Institute of Physics and the Physical Society, The Institution of Structural Engineers, and the Institute of Welding. Mr A. F. C. Brown of the National Physical Laboratory, and representative of the Institution of Mechanical Engineers, has been elected the first chairman of the committee. The Institution of Mechanical Engineers provides the secretariat for the committee.

Morgan Crucible reorganize

On 1 April 1961, as part of a group reorganization, the crucible department of the Morgan Crucible Company Ltd will become a wholly owned subsidiary. It will be called Morganite Crucible Ltd and will operate from Norton, near Worcester, where the company already has a factory. In preparation for this change, the crucible sales department and some of the technical staff are already being transferred from London to Norton.

Communications formerly addressed to the sales or technical departments at Wandsworth, London, should be made to The Morgan Crucible Co. Ltd, Norton Works, Worcester (Worcester 26691, Telex 33191).

New plant and equipment

The Foster Instrument Company Ltd recently announced details of its automatic temperature logging equipment using analogue-to-digital conversion. The makers say that the equipment has been developed with the prime object of providing an inexpensive and technically simple method of automatically measuring the temperature at a large number of stations in a process, and recording the results in a digital form. Each equipment is individually tailored to customers' requirements.

Britain's first liquid helium plant to be run by an industrial organization started service recently at the Morden, Surrey, works of *British Oxygen Research and Development Ltd*. The plant will produce sufficient liquid helium to meet all present demands from industry and research bodies in the UK. The National Physical Laboratory, Teddington, which has run a plant for a number of years, is now gradually discontinuing production and handing over its customers to BORAD. The only other sources of liquid helium in the UK are certain university laboratories where low temperature research is carried out.

Contract news

Distington Engineering Company Ltd, Workington, are to build a vertical continuous casting plant for the production of large slabs, on behalf of Richard Thomas and Baldwins Ltd, for installation in the RTB Panteg works. The machine will be built under licence from Concast AG, Zürich, associates of Distington Engineering Company in the field of continuous casting. The plant will be a single strand unit designed to cast up to 60 in. × 6 in. slabs. Steel qualities of various grades will be cast, especially stainless steel.

Distington are also building a vertical continuous casting plant for billets on behalf of Canara Workshops Ltd, Bangalore, India.

The plant will be a single strand unit designed to cast from 2 in. square to 4 in. square billets but equipped to cast 3½ in. square billets initially. Provision is being made in the structure for the later addition of a second strand. Main qualities to be cast will be silicon manganese steel.

Head Wrightson Iron and Steel Works Engineering Ltd, a subsidiary of Head Wrightson and Co. Ltd, have received an order from Appleby-Frodingham Steel Company for the design and construction of further extensions to their ore preparation and sinter plants. This order covers the supply of four additional sinter machines 8 ft wide by 168 ft long together with the engineering of the complete plant and has a total value of about £1½ m.

The completion of this contract will bring the total number of sinter machines supplied and installed by Head Wrightson to the Appleby-Frodingham Steel Co. to ten.

INDUSTRIAL PUBLICATIONS RECEIVED

Newman Velan forged steel bonnetless globe valves are fully described in an attractive booklet no.315/8/60 recently issued by Newman, Hender and Co. Ltd.

A set of standard classifications and a segregation schedule for aluminium scrap have been issued jointly by the Association of Light Alloy Refiners and Smelters, and the National Association of Non-Ferrous Scrap Metal Merchants. Copies are available from 3 Albemarle Street, London W1.

Inco-Mond Magazine no.15 includes articles on paving modern motorways, corrosion in steam condensers, an engine without moving parts, and how to clean stainless steel.

Leaflet no.470, 'Jaw breakers' has recently been issued by Hadfields Ltd.

Renold Chains Ltd tell how their products 'serve the world's industry' in a recent leaflet.

Zirconite machinable refractory manufactured by W. and C. Spicer Ltd is described in a new folder.

Monograph no.40 (1960) from Hopkin and Williams Ltd deals with 2:9-dimethyl-1:10-phenanthroline, a reagent for copper.

CHANGES OF ADDRESS AND TITLE

Jarrow Metal Industries Ltd, a wholly owned subsidiary of *Armstrong Whitworth (Metal Industries) Ltd* went into liquidation on 30 September. Armstrong Whitworth (Metal Industries) Ltd now operate the steel foundry at Jarrow under their own name, and the address is Western Road Works, Jarrow, Co. Durham (Jarrow 89–7111).

Jessop–Saville (Small Tools) Ltd have moved from their Sheffield works to Eastwood Works, Fitzwilliam Road, Rotherham (Rotherham 77171–4).

Head Wrightson Stockton Forge Ltd, a subsidiary of Head Wrightson and Co. Ltd, has changed its name to Head Wrightson Stockton Ltd.

FORTHCOMING CONFERENCES AND EXHIBITIONS

Pressure vessel research towards better design

At the suggestion of the British Welding Research Association, the Institution of Mechanical Engineers is arranging a symposium on 'Pressure vessel research towards better design', to be held in London on 18 January 1961.

About twelve papers will be discussed during the one-day meeting, broadly covering research and design. The research side will take into account pressure vessel components and attention will be focused on the problems related to pressure vessel nozzles. In the design session it is planned to include papers on comparisons of Continental and British practices and on design codes.

Further details of the arrangements will be announced in due course.

Conference on waste heat recovery

The Institute of Fuel has announced that a summer meeting and conference on waste heat recovery from industrial furnaces will be held in Bournemouth from 15 to 19 May 1961. The conference is intended to bring up to date the book 'Waste heat recovery from industrial furnaces' which emerged from the first conference held in April 1946.

Chairman of the conference will be Dr W. A. MacFarlane, C.B.E., President of the Institute of Fuel, and papers will be presented at five technical sessions under the broad divisions of 'Fundamental principles', 'Types of equipment', and 'Industrial applications'. At the session on industrial applications (iron and steel industry) the chairman will be Mr W. F. Cartwright, D.L., J.P. (*President of The Iron and Steel Institute*), and the rapporteur will be Dr A. H. Leckie of the Iron and Steel Board.

At each session there will be discussion of papers presented, and an exhibition of equipment used in the recovery of waste heat will be held during the conference. Application forms and information are available from the Institute of Fuel, 18 Devonshire Street, Portland Place, London W1.

DIARY

10 Nov. STAFFORDSHIRE IRON AND STEEL INSTITUTE—Presidential address by F. V. Wright—Training Centre, Stewarts and Lloyds Ltd, Bilston, 7.30 pm.

14 Nov. LINCOLNSHIRE IRON AND STEEL INSTITUTE—Lecture, '*The application of research to steelworks refractory problems*', by Dr P. W. Clark—North Lindsay Technical College, Kingsway, Scunthorpe, 7.30 pm.

15 Nov. ROYAL INSTITUTE OF CHEMISTRY—Annual meeting—Shell-Mex House, Strand, London WC2, 6.30 pm.

16 Nov. NORTH WALES METALLURGICAL SOCIETY—Lecture, '*Non-destructive testing*', by N. F. Godwin—Lecture Theatre, Flintshire Technical College, Connah's Quay, nr. Chester, 7 pm.

16 Nov. ROYAL STATISTICAL SOCIETY—Meeting and inaugural address by president, Professor M. G. Kendall—London School of Hygiene, Keppel Street, London W1, 5.15 pm.

16 Nov. INSTITUTION OF MECHANICAL ENGINEERS—Lecture, '*Teaching of metallurgy to engineers*', by Prof. J. G. Ball—1 Birdcage Walk, London SW1, 6 pm.

17 Nov. INSTITUTION OF MINING AND METALLURGY—Meeting—Geological Society, Burlington House, Piccadilly, London W1, 5 pm.

18 Nov. WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Lecture, '*Selection, testing, and use of steel for Caterpillar tractors*', by W. Sellars and W. J. Cormack—39 Elmbank Crescent, Glasgow.

23 Nov. MANCHESTER METALLURGICAL SOCIETY—Lecture, '*New aspects of the electron theory of metals*', by Professor G. V. Raynor—Manchester Literary and Philosophical Society, George Street, Manchester, 6.30 pm.

29 Nov. THE IRON AND STEEL INSTITUTE—13th Hatfield Memorial Lecture—Church House, Great Smith Street, London, SW1, 6.30 pm. (*See p. 353, this issue.*)

29 Nov. SOCIETY OF INSTRUMENT TECHNOLOGY—Symposium, '*Nuclear temperature scanning*'—Manson House, Portland Place, London W1, 7 pm.

29 Nov. INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND—Informal meeting, 'Does prefabrication pay?'—39 Elmbank Crescent, Glasgow, 6.30 pm.

29–30 Nov. THE IRON AND STEEL INSTITUTE—Autumn General Meeting—Church House, Great Smith Street, London SW1 (*see* July 'News', p.341).

29 Nov.–2 Dec. CORROSION AND METAL FINISHING EXHIBITION—Olympia, London.

30 Nov.–2 Dec. THE IRON AND STEEL INSTITUTE (FOR THE BRITISH NUCLEAR ENERGY CONFERENCE)—Symposium, '*Steels for reactor pressure circuits*'—Church House, Great Smith Street, London SW1 (*see* September 'News', p.91).

5 Dec. INSTITUTE OF BRITISH FOUNDRYMEN, SHEFFIELD BRANCH—Lecture, '*Engineering the layout of a jobbing core shop*', by A. Atherton—Technical College, Pond Street, Sheffield, 7 pm.

6 Dec. INSTITUTE OF WELDING, SLOUGH SECTION—Lecture, '*Argon welding process*', by F. W. Copplestone—Lecture Hall, Community Centre, Farnham Road, Slough, 7.30 pm.

7 Dec. MANCHESTER METALLURGICAL SOCIETY—Lecture, '*The relationship between physical test results and engineering performance*', by Dr J. H. Lamble—Manchester Literary and Philosophical Society, George Street, Manchester, 6.30 pm.

7 Dec. THE SOCIETY FOR ANALYTICAL CHEMISTRY—Meeting on the flask combustion technique—Imperial College, Exhibition Road, London SW7, 6.30 pm.

7 Dec. INSTITUTION OF MECHANICAL ENGINEERS (FOR THE BRITISH NUCLEAR ENERGY CONFERENCE)—Symposium on the Dounreay fast reactor—1 Birdcage Walk, London SW1.

7 Dec. THE INSTITUTION OF METALLURGISTS—Informal Christmas dinner and talk, '*Scientific information—the rake's progress*', by B. Fullman—Ayrton Hall, Imperial College Exhibition Road, London SW7, 6.15 for 7 pm.

7 Dec. INSTITUTE OF PETROLEUM—Lecture, '*The changing energy pattern in Europe and its possible effect on product-mix*', by M. E. Hubbard—61 New Cavendish Street, London W1, 5.30 pm.

8 Dec. STAFFORDSHIRE IRON AND STEEL INSTITUTE—Lecture, '*The Ajax furnace and process*', by A. Jackson—Training Centre, Stewarts and Lloyds Ltd, Bilston, 7.30 pm.

12–15 Dec. AMERICAN NUCLEAR SOCIETY—Winter meeting—Mark Hopkins Hotel, San Francisco.

12 Dec. LINCOLNSHIRE IRON AND STEEL INSTITUTE—Lecture, '*The technique of vertical and horizontal rolling*', by T. Hessey—North Lindsey Technical College, Scunthorpe, 7.30 pm.

14 Dec. INSTITUTE OF WELDING—Lecture, '*Welding of transportation pipelines*', by R. J. Wright—54 Princes Gate, London SW7, 7.30 pm.

14 Dec. SOCIETY FOR INSTRUMENT TECHNOLOGY—Lecture, '*Speed control of aircraft gas turbines for jet propulsion*', by R. J. Walsh—Manson House, Portland Place, London W1, 7 pm.

15–16 Dec. POWDER METALLURGY JOINT GROUP—Wintermeeting—Church House, Great Smith Street, London SW1. (*See p. 352, this issue.*)

15 Dec. INSTITUTE OF MINING AND METALLURGY—Meeting—Geological Society, Burlington House, Piccadilly, London W1, 5 pm.

15 Dec. NORTH WALES METALLURGICAL SOCIETY—Joint meeting with the Society of Instrument Technology, '*Instrumentation in steelmaking*', by Dr P. Bacon—Lecture Theatre, Flintshire Technical College, Connah's Quay, nr. Chester, 7 pm.

16 Dec. WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Lecture, '*Recent developments in refractories for iron and steelmaking*', by R. Malcolm—39 Elmbank Crescent, Glasgow, 6.45 pm.

20 Dec. INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND—Joint meeting with Institute of of Marine Engineers, Scottish section, and Greenock Association of Engineers and Shipbuilders, '*Developments in marine steam turbine design*', by T. W. F. Brown—39 Elmbank Crescent, Glasgow, 6.30 pm.

BRITISH IRON AND STEEL INDUSTRY TRANSLATION SERVICE

The following translations are now available, in addition to those given on page 228 of the October 1960 issue of the *Journal*:

Study on hot ductility of steels. II—Hot ductility of the austenitic stainless steels.
MORISHIMA, T., *Tetsu-to-Hagane*, 1958, June, pp.660–668. (£8) **[1632**

Studies on the rolling of seamless steel tubes. III—Effect of rolling conditions on the various loads of a plug mill.
SATO, K., *Tetsu-to-Hagane*, 1958, March, pp.386–388. (£5 15*s.* 0*d.*) **[1667**

The causes for the disintegration of hot-blast stove and checker bricks made of fireclay.
KIENOW, S., *Stahl u. Eisen*, 1960, March 3, pp.285–289. (£3 15*s.* 0*d.*) **[1678**

Modern methods of control with mutators for heavy drives.
ZWICKY, R., *Bull. Assoc. Suisse Electr.*, 1956, (5), pp.155–159. (£3 10*s.* 0*d.*) **[1698**

The decade system for automatic positioning of the edging stand screw-down.
STROBL, K., *ELIN-Zeitschrift*, 1958, March, pp.12–29. (£5 5*s.* 0*d.*) **[1701**

The transport of large quantities of material as an engineering problem in modern iron and steel technology.
HÜSER, K. H., *Stahl u. Eisen*, 1960, Jan. 7, pp.1–12. (£7 0*s.* 0*d.*) **[1729**

The structural and thermodynamical foundations of liquid metallurgical slag reactions.
NEGRESCU, T., *Studii si Cercetari de Metallurgie* (Bucarest), 1958, (2), pp.161–202. (£10). **[1754**

Investigations into the recrystallization of an austenitic chromium–nickel steel with special stress on prolonged heating.
BORCHERS, H. *et al.*, *Arch. Eisenhütt.*, 1960, April, pp.237–242. (£3 5*s.* 0*d.*) **[1768**

Contribution to the spectrochemical microanalysis of oxide inclusions isolated from steels.
LUDEMANN, K.-F. *et al.*, *Neue Hütte*, 1960, April, pp.238–244. (£4 0*s.* 0*d.*) **[1771**

The economics of a continuous light-section rolling mill.
ANTONI, W. A., and SCHNEIDER, E., *Stahl u. Eisen*, 1960, May 12, pp.641–652. (£8 5*s.* 0*d.*) **[1778**

What is new in the aluminizing of iron.
KARASEVICH, V. I., and PRIKHOD'KO, V. E., *Tsvetnye Met.*, 1959, (10), pp.68–75. (£5 5*s.* 0*d.*) **[1781**

Starting torques for tightening bolted joints.
KELLERMANN, R., and KLEIN, H.-CH., *Werkstattstechnik*, 1960, April, pp.192–195. (£2 5*s.*) **[1787**

Spectrophotometric determination of small amounts of niobium and tantalum in stainless steels.
ROSOTTE, R., and JAUDON, E., *Chim. Anal.*, 1959, June, pp.229–239. (£3 15*s.* 0*d.*) **[1794**

The influence of copper on the recrystallization temperature of low-carbon steels.
ZIDEK, M., *Hutnicke Listy*, 1959, Nov., pp.943–947. (£5) **[1807**

Thermoelectric method of measuring the metal surface level in continuous casting.
ELKERSHAUSEN, A., *Neue Hütte*, 1960, Jan., pp.31–36. (£4 0*s.* 0*d.*) **[1809**

Metallurgical considerations in the welding of stainless and high-temperature steels.
BERNSTEIN, A., *Schweissen u. Schneiden*, 1960, Feb., pp.55–61. (£4 0*s.* 0*d.*) **[1811**

The limits of dephosphorization of iron with lime.
TRÖMEL, G., and OELSEN, W., *Arch. Eisenhütt.*, 1955, Sept., pp.497–506. (£5 15*s.* 0*d.*) **[1812**

Ingot moulds from nodular cast iron.
KÖRÖS, B., *Koh. Lapok-Öntöde*, 1959, April, pp.111–113. (£3) **[1814**

Brittleness of special steels in the as-cast condition: influence of impurities.
CASTRO, R., and GUEUSSIER, A., *Rev. Mét.*, 1960, Feb., pp.135–148. (£7 5*s.* 0*d.*) **[1816**

The solubility relationships and the precipitation of vanadium nitride in the α- and γ-regions of the system iron–nitrogen–vanadium.
FROHBERG, M. G., and GRAF, H., *Stahl Eisen*, 1960, (8), April 14, pp.539–541. (£2 10*s.* 0*d.*) **[1821**

Internal stresses in quenched steels.
BORCHERS, H., and SAFFERLING, A., *Stahl Eisen*, 1960, (8), April 14, pp.541–546. (£4 10*s.* 0*d.*) **[1822**

Shrinking wheels on to axle shafts.
WÄCHTER, A., *Deutsche Eisenbahntechnik*, 1960, (2), pp.84–86. (£2 5*s.* 0*d.*) **[1825**

Continuous railway tracks.
DEENIK, J. F., *Der Eisenbahn Ingenieur*, 1960, July, pp.203–207. (£4 0*s.* 0*d.*) **[1829**

The reprofiling of used rails at the Saint Dizier workshops.
WAUTHIER, M., and VENNIN, M., *Rev. Gén. Chem. Fer.*, 1960, July–Aug., pp.401–403. (£1 15*s.* 0*d.*) **[1830**

Contribution to the problem of the life of steel moulds for centrifugal casting.
BÜHLER, H., *Stahl u. Eisen*, 1959, Nov. 12, pp.1722–1730. (£5 10*s.* 0*d.*) **[1833**

Studies on the life of steel moulds for centrifugal casting.
KÖNIGER, A., and LIEBMANN, W., *Stahl u. Eisen*, 1959, Nov. 12, pp.1730–1742. (£8 15*s.*) **[1834**

A general outline of the work of TsNIITMASh (Central Scientific Research Institute for Technology and Engineering).
TSNNTRAL'NYI MAUCHNO-ISSLEDOVATEL'SKII INSTITUT TEKHNOLOGII I MASHINOSTROENIYA, Moscow, 1959, pp.79. (£5 0*s.* 0*d.*) **[1837**

Increasing the speed of charging conveyors in a sinter plant.
PRITYKIN, D. P., *Metallurg*, 1959, (10), pp.4–6. (£2) **[1838**

Effect of the nature of the wood on the corrosion of light-alloy screws in sea water.
PANSERI, C., and LUFT, G., *Alluminio* 1960, Jan., pp.5–20. (£7 10*s.* 0*d.*) **[1867**

Experiments on the automatic ultrasonic testing of welds.
ANGRES, J., *Schweisstechnik*, 1960, (4), pp.124–127. (£3 5*s.* 0*d.*) **[1880**

Condensation method of dust separation for precipitation of mining dust.
DERYAGIN, B. V., and MIKHELSON, M. L. *Izvestiya AN, SSSR, OTN, Met. Topliva*, 1959, (2), pp.124–138. (£6 5*s.* 0*d.*) **[1883**

Effect of stability of a 0·5%Cr–0·5%Mo steel on the rupture/time curve at 500°C.
BÄCKER, L. *et al.*, Int. Disc. on 'Long-time behaviour of high-temp. steels', Düsseldorf, 1960, June 24 and 25. Paper No.12. (£2 15*s.*) **[1914**

The granulation of reducing manganese-bearing slags.
CHIKASHUA, D. S. *et al.*, *Stal'*, 1957, July, pp.611–615. (£4 0*s.* 0*d.*) **[1921**

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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*Abstracts, the reference to which is marked with an asterisk, are or are to be available as translations.

ABSTRACTS

These abstracts are also available on index cards in advance of publication in the *Journal*, each abstract being classified under the Universal Decimal system (UDC). Details and subscription notes can be obtained from the Secretary, The Iron and Steel Institute.

MINERAL RESOURCES

Genesis of marine sedimentary iron ores H. Borchert (*Bull. Inst. Min. Met.*, 1960, **69,** June, 530–539) A report of discussion on the paper.

Cryptomelanine and Jaspilite deposits in Corumba, Mato Grosso, Brazil H. Putzer (*Eng. Min. e Met.*, 1959, **30,** Nov., 267–270; Dec., 335–338) [In Portuguese] The locale and geology of these deposits are discussed. Details of the Mn ore bodies (cryptomelanine) are given; exploitation is considered and reserves are estimated at $33{\cdot}7 \times 10^6$ t. The geology of the iron ore deposits is described in the second part of the article. With over 4×10^{10} t, the reserves are among the largest in the world (15 refs).

Metal and industrial mineral mines W. K. Buck (*Canad. Dept. Mines Techn. Surveys Min. Res. Div., Operators List* 2, 1959, Aug., pp.27) Iron Mines are listed, pp.12–13.

A detailed look at present supplies: world molybdenum and tungsten resources R. C. Nelson (*Eng. Min. J.*, 1960 **161,** May, 93–97) A list of world deposits.

The occurrence of native nickel-iron in the serpentine rock of the Eastern Townships of Quebec Province E. H. Nickel (*Canada Dept. Mines Techn. Surveys, Res. Rep. R57, from Canadian Mineralogist*, 1959, **6** (3), 307–319) The occurrence of this ore, and its chemical analysis, structure, and origin are discussed (10 refs).

ORES—MINING AND TREATMENT

Underground development at abandoned open pit Hull Iron Mines Ltd (*Min. J.*, 1960, **254,** May 27, 612–613) Sinking of an incline and of a three-compartment shaft has given access to an ore body in Quebec.

Putting a valuation on the field of iron ore at Fort Gouraud (*Mines Mét.*, 1960, May, 276) An agreement signed in Washington on 17 March 1960 for a loan by the International Bank, guaranteed by the Governments of France and Morocco, for the working of the iron deposits known to exist in the interior of French Morocco at Fort Gouraud, has been granted to financial interests, including Rothschild Brothers, for the construction of a French railway of 675 km from Port Etienne, thus by-passing the Spanish enclave of Rio de Oro (which would provide a shorter route of 350 km to the port of Cisneros) is briefly defined.—S.H.-S.

Milling plants in Canada: metallic ores: list 3, part I W. K. Buck (*Canad. Dept. Mines Techn. Surveys, Min. Res. Div.*, 1959, June, pp.49) Plants are tabulated. **Part 2: Industrial minerals** (1959, Oct., pp.43).

Ore—microscopical studies of the manganese ore-minerals of old M.P. II. Satak, Beldongri, Lohdongri and Kachurwahi, Nagpar District S. P. Deshpande (*Proc. Indian Acad. Sci.*, 1960, **51A,** April, 202–218) Spot tests are described.

The under-sea mining of iron ore at Diélette ~. Cocude (*Mines Mét.*, 1960, 275) The working of the under-sea mine of Diélette, 25 km S. of Cherbourg, with an output of over 100000 t per annum of magnetite–hematite ore (of which Great Britain in 1958 took 46%) is briefly described.—S.H.-S.

Pilot plant studies of the beneficiation of ferruginous manganese ores by the patented process developed at the N.M.L. (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 36) Samples from five sources were tested with varying success.

Studies on the beneficiation of a nickeliferous ore from Ranakpur Mines, Pali district, Rajasthan (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 16) The work so far has been unsuccessful.

Beneficiation of low-grade manganese ore (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 13–15) Studies on ores from six locations are outlined.

Magnetic testing of roasted iron ores A. Szombatfalvy (*Koh. Lapok*, 1959, **14,** Nov., 522–524) The magnetic testing of roasted iron ores with the Siemens 'Ferrograph' Type FO–731 is described.—P.K.

Oxidation of pyrite by iron sulphate solutions R. M. Garrels and M. E. Thompson (*Am. J. Sci., Bradley Volume*, 1960, **258–A,** 57–67) Pyrites from three localities were tested and the classic reaction appeared to be confirmed. Kinetics are discussed.

Utilization of vanadium-bearing titaniferous magnetite deposits of Singhbhum and Mayurbhanj (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 23) Salt-roasting and chlorination were tried and appear promising.

Agglomeration of minerals in a rotary furnace ~. Ladouce (*Centre Doc. Sidér. Cir.*, 1960, (2), 411–427) The construction and operation of a rotary furnace is described, together with a review of the work of a sub-commission on Agglomeration under the auspices of l'Association Technique de la Sidérurgie Français (ATSF).—S.H.-S.

Inland Steel expands its sintering plant facilities C. Longenecker (*Blast Furn. Steel Plant*, 1960, **48,** April, 345–349) A description of the new screening and sinter plant equipment being laid down by Inland Steel.

The sintering of flotation concentrates O. Nyquist (*Jernkont. Ann.*, 1960, **144,** (2), 133–163) Difficulties in sintering can be due partly to the flotation reagents and partly to the fine particle size of the concentrates. Methods of improving results by adding surface-active agents to increase bulk density, and by obtaining more rapid sintering are discussed (21 refs).

Self-fluxing sinter: experimental production for Italian blast furnaces G. Sironi (*Iron Coal Trades Rev.*, 1960, **180,** April 15, 851–853) A study on an experimental sinter pan by the Finsider Co. is reported. Effects of basicity, size distribution, reducibility and sulphur elimination were examined, and the results are shown graphically. Coke proportion and its effect on mechanical strength, effects of limestone addition on reducibility and on coke rate, and optimum conditions for S removal are given.

Reconstruction of rotor fans G. F. Chub (*Stal'*, 1960, (6), 494) A note from Zaporozhstal'. Increasing blade width 25% raised sinter production by 3·88%; increasing rotor dia. to 2080 mm had already increased production by 4·86%.

A contribution to the problem of the advantages of cold sinter in blast furnace smelting S. I. Eliasberg (*Stal'*, 1960, (6), 484–487) With the development of satisfactory sinter cooling plants, screening for the removal of fines is advocated, particularly when using a 100% sinter charge.

Replacing different amounts of limestone in the sinter mix with its equivalent of lime G. F. Chub (*Stal'*, 1960, (6), 495) A note from Zaporozhstal'. Sintering is accelerated by small amounts of replacement but above 5% no further effect is produced.

Increasing the sintering area of a sintering machine A. V. Drumbo and D. P. Pritykin (*Stal'*, 1960, (6), 481–484) A new pallet design with curved sides increased the area of a machine at Zaporozhstal' from 50 to 62·5 m². The fans were also reconstructed.

Magnetic properties of sinter from mixes with different carbon contents Z. I. Nekrasov, N. A. Gladkov, and V. V. Chekin (*Stal'*, 1960, (6), 488–491) Degree of magnetization is proportional to Fe_3O_4 content; there was no particular relationship to sinter properties. Magnetization varies considerably with carbon content, with a maximum at 5%C, which also corresponds to optimum conditions for sintering.

FUEL—PREPARATION, PROPERTIES AND USES

A graphical method of studying the coking of coals M. Weltner (*Koh. Lapok*, 1959, **14,** July, 321–326) A new instrument, the 'Paulik derivatograph' is described which is used in Hungary for studying the coking reactions of coals by means of thermo-gravimetry and differential thermal analysis.—P.K.

Heat balance of coke ovens D. Dioszeghy (*Koh. Lapok*, 1959, **14,** Oct., 448–453) A 'method of drawing up' a heat balance-sheet for a coke oven is shown.—P.K.

Coke battery stacks—their construction,

maintenance and failures R. A. Washburn (*Blast Furn. Steel Plant*, 1960, **48,** April, 361–364) The article refers to the coke oven plants of the Indiana Harbor Works of Inland Steel Co.

Report on the operation of the coking plant of 'Dunai Vasmü' G. Pesti (*Koh. Lapok*, 1959, **14,** Sept., 415–422) The author reports on the operation of this coking plant in Hungary and notes some problems concerning the quality of coke, optimum capacity of the plant, chemical by-products, and consumption of power that must be solved in future.—P.K.

Effect of rate of coking and of final coking temperature on the properties of coke H. Echterhoff (*Gluckhauf*, 1960, **96,** July 16, 929–941) Size of the coke lumps and strength of the coke decrease with increasing rate of coking, particularly strength is adversely affected. Chemical and physical tests showed the decisive effect of the final coking temp. on the coke properties, whereas no such influence, apart from those mentioned above, was found for the coking rate. The results of tests are shown in many tables and graphs.—T.G.

Improvement of metallurgical coke quality D. A. Hall and J. Gordon (*Gas World-Coking*, 1960, **151,** June 4, 93–100, 102) Blending requirements with Durham coal in a test oven are described.

The mineral matter content of coke J. E. Barker and R. A. Mott (*Fuel*, 1960, **39,** July, 363–365) A letter. Equations for reduction to a mineral-matter-free basis are given for various states of combination of Fe.

TEMPERATURE MEASUREMENT AND CONTROL

Platinum platinum/rhodium thermocouples for temperature measurement in the foundry E. R. Perry (*Found. Trade J.*, 1960, **108,** April 14, 457–461) A review of current practice with an account of the development of a rare-metal couple of improved strength.

Still hotter horizons for thermocouples (*Engineering*, 1960, **189,** June 17, 806–807) A review of metallic and the new non-metallic couples and of sheathing and insulating materials.

REFRACTORY MATERIALS

Recent research in refractories at the University of Sheffield J. White (*Refract. J.*, 1960, **26,** March, 60–73) A lecture. Phase equilibria in basic refractories and in systems containing iron oxides (with part of the MgO–FeO–Fe_2O_3 system up to 1650°C), sintering mechanism with reference to contact of drops, solid state sintering, bonding mechanisms, and thermal stresses are surveyed (48 refs).

Production of basic and special refractories from indigenous sources (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 17–20) Almorah magnesite, dolomites, and chrome ores were studied and the production of chrome–magnesite, metal-clad basic refractories. A magnesite crucible for h f induction furnaces, super-duty silica brick, mullite from kyanite, calcium–aluminate cement, and various graphite products were examined. The use of Assam sillimanite was also considered.

Sillimanite and kyanite insulating bricks V. S. Bhuta and M. L. Misra (*Refract. J.*, 1960, **26,** March, 76–77) Fireclay was used as binder and successful trials were carried out.

Fire-clay bricks for blast furnace lining F. Nagy (*Koh. Lapok*, 1959, **14,** Oct., 459–463) Experiments on the production of fire-clay shaped bricks for blast-furnace lining in the Hungarian Refractory Works, Budapest, between 1951 and 1958 are described.—P.K.

Basic oxygen furnace refractories B. L. Dorsey (*Amer. Ceram. Soc. Bull.*, 1960, **39,** May 15, 261–263) This article describes experiences with refractories in basic oxygen steelmaking practice. Analyses of refractories tried are given. The results of a study on commercial tar-bonded dolomite-magnesia refractories in use at the Aliquippa Works of the Jones & Laughlin Steel Corp. are as follows; there was no apparent correlation between service and interval of time between receipt and burn-in; the higher Si metal appeared to lessen service life of these refractories, and linings with longer time intervals between heats give shorter service.

Carbon bricks A. Cser (*Koh. Lapok*, 1959, **14,** Sept., 410–414) The use, properties, and production of carbon bricks are reviewed in the paper.—P.K.

Transparent crucible material for high temperatures R. C. DeVries and C. F. Moehle (*Amer. Ceram. Soc. Bull.*, 1960, **39,** May 15, 270–271) MgO single crystals can be fabricated easily into transparent crucibles in which such reactions as crystal growth, solidification, or melting in certain systems can readily be observed. Rectangular single crystal blocks are cleaved from massive single crystals. A square or rectangular hole with sides parallel to the block is drilled. Capacity of the crucibles used ranged from about 0·1 to 1·0 cc. The resistance heating wire can be wound directly on the crucible. The observations are made with a microscope through the cleaved surfaces of the crystal and between the coils of the heating wire.

The lining of induction vacuum furnaces A. V. Frolov and V. P. Grechin (*Stal'*, 1960, (6), 515–517) Studies on the reaction of a Ni alloy with various crucible linings were made. Rammed and fused MgO, Al_2O_3, ZrO_2, and unfused BeO were compared. Fused magnesite and electric corundum were best up to 1450–1530°C, crucible life being 60–200 heats. H_3BO_3 was unsuitable for bonding. CaF_2 is better for magnesite and dextrin for corundum.

An internally wound platinum rhodium furnace for use in air up to 1900°C P. D. S. St Pierre (*Amer. Ceram. Soc. Bull.*, 1960, **39,** May 15, 264–266) Details of furnace construction are given together with a note on a thermocouple for use in air at 1850°C. Features of the furnace are the simplicity of construction, that there are no expensive manufactured refractories required, and the ability to operate at high temp. in an oxidizing atmosphere.

Electron microscope studies of mullite development in fired kaolinites J. J. Comer (*J. Amer. Ceram. Soc.*, 1950, **43,** July, 378–384) Well and poorly crystallized kaolinites were heated at 850–1200°C and preferred orientation of mullite was observed on the former.

Examination of a simple measuring procedure for the determination of spalling resistance R. Bahn and K. Pump (*Silikat Technik*, 1959, April, 190–192) Spalling resistance of ceramic materials is determined by measuring bending (transverse) strength as a function of thermal shock. Test results on sintered corundum are reported.

Thermal shock resistance C. Radford (*Ceramics*, 1960, **11,** April, 16–19) Tests on various materials including refractories are referred to. Effects of thermal conditioning are shown.

IRON AND STEEL—GENERAL

Development of iron and steel industries in India N. N. Sen (*Sci. Eng.*, 1960, **13,** March–April, 37–45) Ore and coal pretreatments, blast conditioning, uses of O_2, the LD and low-shaft furnaces are briefly reviewed with a note on research and development.

New processes in an integrated iron- and steelworks layout W. F. Cartwright (*JISI*, 1960, **196,** Nov., 249–252) [This issue].

China's iron and steelworks—4: Chungking and Szechuan Province (*Met. Bull.*, 1960, June 24, i, iv) A brief account of products and output.

Consideration of the problem of power utilization in Spanish iron and steelmaking plants J. J. Alzugaray Aguirre (*Dyna*, 1960, **35,** May, 371–379) [In Spanish] The influence of the industry on the Spanish fuel economy, the sources of primary and secondary energy, the distribution and use of energy in a typical integrated iron and steelworks and Spanish gas production are considered in turn. The possibilities of using other energy sources in the industry and more efficient utilization of power are also considered.—P.S.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Improved blast furnace lining life at Colorado Fuel and Iron Corp. J. W. Carlson, A. E. Frey, and D. Malwitz (*Iron Steel Eng.*, 1960, **37,** April, 119–125) Improved practice leading to greatly improved lining life at C. F. & I.'s Pueblo plant is attributed to more careful construction, better ceramics in the stack and bosh, carbon hearths, and improved taphole practice. Some details are given.

The new blast furnace at the Denain works of Usinor (*Rev. Mét.*, 1960, **57,** March, 199–206) A detailed description of the No.5 blast-furnace recently installed, its construction, capacity, ancillary equipment, and operating data.

Micro-venturi technique applied to the operation of smelting plant and blast furnaces V. Litchinko (*Centre Doc. Sidér. Circ.*, 1960, (2), 451–458) Various economic advantages based on experiments with micro-venturis at the Knutange plant are defined and summarized.

Automation of blast furnaces in the USSR V. T. Baszov (*Koh. Lapok*, 1959, **14,** Aug., 362–368) The author describes the present state and future prospects of mechanization and automation of blast-furnaces in the Soviet Union.—P.K.

Coke consumption in the blast furnace and the reactivity of the coke G. Heynert, W. Zischkale, and E. Schürmann (*Stahl Eisen*, 1960, **80,** July 21, 981–990) An iron smelter who uses coke supplied from various sources found that the coke consumption could not be calculated from chemical or physical values, but that some other effect must be present. It was observed that this is the reactivity of the coke with CO_2 in the blast-furnace. It is advantageous to use a coke that shows a low reactivity with CO_2. The results of studies on the blast-furnace and of a specially developed test are reported. In the discussion, it is pointed out that the reactivity of the coke must not be too low, particularly when producing foundry or haematite iron.—T.G.

Gunning of hot blast main linings R. N. Ames and Q. J. Schiene (*Blast Furn. Steel Plant*, 1960, **48,** April, 357–360) Trials leading to the use of a monolithic lining are described. Linings have already lasted up to three years without deterioration.

Even distribution of blast air through blast-furnace tuyeres ~. Tavard (*Centre Doc. Sidér. Circ.*, 1960, (2), 429–436) The operation of blast-furnace 7 at Homécourt is described.

Automatic control of blast furnace stoves E. A. Burlo and V. V. Burtsev (*Stal'*, 1960, (6), 491–495) Innovations at Kuznetsk are described. Blast temp. was raised and the efficiency of stove changing was greatly improved and manual operation was eliminated.

A test of ferro-coke in U.S.A. C.-G. Thibaut (*Centre Doc. Sider. Circ.*, 1960, (2), 437–448) A report on a series of tests carried out at Everett Mass., in the operation of a blast-furnace with and without ferro-coke, with comparative tables of operation and products under both systems and an analysis of results is given.

Experience with sludge pipes V. D. Sleptsov (*Stal'*, 1960, (6), 572–574) Methods of clearing pipe-lines carrying sludge suspensions are described, but in designing gas purifier systems chemical treatment to prevent deposit formation is recommended.

Investigations of the influence of catalysis on the decomposition of carbon monoxide H. Schenck and W. Maschlanka (*Arch. Eisenh.*, 1960, **31,** May, 271–277) The influence of metallic iron as a catalyst in the reaction $2CO \rightleftharpoons C + CO_2$ is examined, with reference to conditions in the blast-furnace, for various temp. gas velocities and compositions, and conditions of the catalyst. It is shown that traces of SO_2 and H_2S can act as irreversible catalyst poisons, and other gases, which may be present in the blast-furnace, can behave as irreversible poisons also (21 refs).

Continuous pre-refining of pig iron in the blast furnace tap channel by blowing pure oxygen through porous blocks P. Leroy and R. Simon (*Inst. Hierro Acero*, 1960, **8,** Jan., Special Number, 40–59) Details of the operation of the pilot plant at Moyeuvre are given and the metallurgical aspects are described (11 refs).—P.S.

Preparation of low-phosphorus iron from phosphoric metal L. Cook (*Iron Coal Trades Rev.*, 1960, **180,** June 10, 1301–1307) Trials in a Kaldo converter and on a laboratory scale using powder injections are reported, also foundry trials and work on a pilot plant.

Solid state reduction of ilmenite G. Östberg

(*Jernkont. Ann.*, 1960, **144,** (1), 46–76) [In English] The rate of reduction with CO and H, and the influence of alkali, B_2O_3, and P_2O_5 additions on the reduction process were examined. Rate of reduction with CO was found to be of the same order of magnitude for an ilmenite concentrate as for a magnetite concentrate at 1 100–1 200°C. Methods of coarsening the Fe particles are discussed, and applied to magnetic separation. Results indicated that solid state reduction and mechanical separation can produce satisfactory iron and Ti oxide concentrate (50 refs).

The influence of the oxides of magnesium and aluminium on the reaction equilibria of manganese between carbon saturated silicon-containing iron and lime-silica slags at 1500°C H. Schenck and F. Neumann (*Arch. Eisenh.*, 1960, **31,** March, 199) cf. *ibid.*, 1960, **31,** Feb., 83–86. A correction to the captions of the ordinates to Fig.8*a–c*, which should run from top to bottom: 0·4–0·3–0·2–0·1–0.

Direct reduction processes. Applications to iron ores of interest to the French iron and steel industry J. Astier (*Rev. Mét.*, 1960, **57,** March, 191–198) Various direct reduction processes for making sponge iron, molten iron, or concentrates are described (20 refs).

Manufacture of sponge iron by 'Hojalata y Lamina' in Monterey, Mexico M. Thibau (*Eng. Min. e Met.*, 1959, **30,** Nov., 287–288) [In Portuguese] Brief details of the process are given.—P.S.

Sponge iron production by the Hoganas process using RS coal, MG haematite and wood charcoal Y. Wahlberg and A. G. Lopes (*Eng. Min. e Met.*, 1959, Sept., 137–144) [In Portuguese].

Renn test with Portuguese iron ore and coal L. de Castro e Solla and J. L. Guimaraes dos Santos (*Inst. Hierro Acero*, 1960, **8,** Jan., Special Number, 30–39) The results of trials with Portuguese raw materials in the Krupp–Renn pilot plant at Rheinhausen are reported. The ore was Moncorvo haematite, containing about 39% total iron and 34% silica, and the anthracite fines, containing about 24% ash, came from Pejac. Both materials were found to be well suited to the process (16 refs).—P.S.

Compact heat exchanger is an important component for the H-iron process [Air Preheater Corp.] (*Indust. Heat.*, 1960, **27,** Feb., 324) In this process using hydrogen to reduce fluidized iron ore fines, the ore is preheated at 900°F. A Fin-Pak heat exchanger, of size $7 \times 4\frac{1}{2} \times 2\frac{1}{2}$ ft, uses waste gases from the furnace to preheat air to 635°F.—K.E.J.

PROPERTIES, TREATMENT, AND USE OF SLAGS

The structural and thermodynamical foundations of liquid metallurgical slag reactions T. T. Negrescu (*Studii Cercet. Met.*, 1958, **3,** (2), 161–202) A discussion on a general basis of activity theory of basicity and radical replacement processes in slags. An attempt is made to identify the atomic groupings probably present and to assess affinities for oxygen and sulphur. Expressions for the amount of lime free to combine with S are obtained. Al_2O_3 does not contribute to basicity.

Portland blast furnace slag cement: its composition, properties and uses K. K. Nambiar and K. F. Antia (*J. Inst. Eng. (India)*, 1959, **40,** Dec., 355–361).

PRODUCTION OF STEEL

New process for bottom blowing with high pressure oxygen G. Savard, R. Lee, and M. R. Campbell (*AIMME, Proc. OH Comm.*, 1959, **42,** 202–216) The authors describe the development of a new process for pre-treatment of hot metal by bottom-blowing with pure O_2 at pressures above 400 lb/in². The process operates at high efficiency, produces good heat recovery, has a good mixing action, and good utilization of millscale, and low fume generation. Results obtained in pilot plant experiments by Canadian Liquid Air Co. Ltd. are discussed, and the possibility of extending the method to a continuous steelmaking process is considered.—G.F.

The physics of oxygen steelmaking C. Holden and A. Hogg (*JISI*, 1960, **196,** Nov., 318–332) [This issue].

The use of models for investigations of oxygen steelmaking processes B. S. Holmes and M. W. Thring (*JISI*, 1960, **196,** Nov., 259–261) [This issue].

Burning away the bears in the converter mouth during blowing with oxygen W. Bading (*Stahl Eisen*, 1960, **80,** June 23, 861–862) It is difficult and time-consuming to burn away a bear that has formed in the converter mouth. The better way is to avoid its formation. Attempts were made to introduce O_2 into the converter mouth for preventing such a formation, but when the converter was tilted, combustible gases entered the switched-off oxygen piping, causing explosions. The modification reported allows air to blow through the oxygen piping when the oxygen is switched off. No explosions have occurred since.—T.G.

New knowledge on the surface blowing of phosphorus-rich pig iron with pure oxygen K. G. Speith, H. von Ende, F. Bardenheuer (*Stahl Eisen*, 1960, **80,** May 26, 733–736) A lance has been developed that allows a predetermined distribution of the O_2 between slag and bath. Using this lance it was possible to produce a steel of only 0·030%P from P-rich pig iron. The steel was also low in N_2 and O_2. Limestone was used as slag former. The total blowing time was 14 min, in the first 12 min the P content was reduced to less than 0·2% (16 refs).—T.G.

A model experiment to study the rate of gas evolution from the bath of an LD converter J. M. van Langen (*JISI*, 1960, **196,** Nov., 262–264) [This issue].

Pilot plant production of steel by the L.D. process (*Nat. Met. Lab., Ann. Rep.*, 1958–59, 34) A short description is given of top blowing with O_2 to standardize the techniques of refining normal high-Si, medium P, Indian pig iron and catching carbon at the right level. A chemical analysis of the product is given.

A model study of splashing Kun Li (*JISI*, 1960, **196,** Nov., 275–280) [This issue].

The basic oxygen process at Jones and Laughlin D. R. Loughrey (*AIMME, Proc. OH Comm.*, 1959, **42,** 274–285) The new L–D converter shop at Aliquippa Works of Jones and Laughlin Steel Corp. began operation in 1957. The author describes the design and layout of the charging, furnace, and teeming bays and of the dust collection system, and then gives details of the blowing procedure. Operating data are summarized, and the quality of the product is briefly considered.—G.F.

The dynamics of the blowing process T. Kootz (*JISI*, 1960, **196,** Nov., 253–259) [This issue].

New process at Kaiser Plant W. F. Bowers (*AIMME, Proc. OH Comm.*, 1959, **42,** 286–287) The L–D process is operating at the Fontana plant of Kaiser Steel Corp. Brief details are given of the plant and its operation, and a summary of operating data is presented.

New steelmaking facilities at the Acme Steel Company C. J. Petry (*AIMME, Proc. OH Comm.*, 1959, **42,** 288–297) The planned new steelmaking facilities at Acme Steel Co. incorporate two hot-blast cupolas and two top-blown oxygen converters, designed to produce 37 500 t of steel per month. Details are given of the cupolas, converters, O_2 plant, and ancillary equipment.—G.F.

Basic oxygen steel process at Algoma C. C. Benton (*AIMME, Proc. OH Comm.*, 1959, **42,** 298–300) The L–D process has been in operation at Algoma Steel Corp. since Nov. 1958. The author summarizes the first five months' operating experience and discusses the progress made in developing the most economical charge composition.—G.F.

Basic oxygen steelmaking A. Decker and P. Metz (*Iron Coal Trades Rev.*, 1960, **180,** March 4, 521–528) A report on the development and operation of the O_2 and lime-blowing converter process given to the Liège section of the Centre National de Recherches Métallurgiques, with some comparison with other processes.

The advantages of using scrap in converter production S. G. Afanas'ev and B. E. Gurevich (*Metallurg.*, 1959, (12), 16–18) In the converter production of steel with oxygen blowing, more heat escapes at the top than is needed for heating the bath to the required temp. The total quantity of cooler necessary to ensure the normal final temp. of the metal, converted to scrap, attains 20–30% of the weight of the iron. By using steel scrap as cooler, great advantages are obtained. No large quantity of Si is introduced into the bath which would otherwise be used for slagging up additional lime, and this adversely affects the linings.

Flame intensity acts as guide for oxygen steel process Jones & Laughlin Steel Corp. (*Iron Age*, 1960, **185,** April 21, 156–157) The use of an instrument for measuring the flame intensity and thus the progress of reaction of an oxygen-blown steelmaking process is reported.—D.L.C.F.

Sparrows Point No.4 open hearth F. J. Broglie and G. L. Cox (*AIMME, Proc. OH Comm.*, 1959, **42,** 38–49) The authors discuss the major considerations taken into account in designing the new No.4 OH shop at the Sparrows Point plant of Bethlehem Steel Co. The furnace constructed is described with particular reference to the gas and air system, and details are also given of the auxiliary equipment, raw materials handling, and furnace charging, steel and slag handling, and mould practice. Recent production data indicate a tonnage rate of 39 t/h from the 395-t furnaces.

The development of open-hearth steel production in Western Germany since 1950 and the present state of productivity and costs W. Kahnis and H. Wubbenhorst (*Stahl Eisen*, 1960, **80,** May 26, 721–733) The capacity for the production of OH steel has not maintained its proportion of the total capacity for the production of steel in Western Germany since 1953 and it is expected that it will fall further in the near future, in spite of the substantial progress that has been made in OH practice. The effect of raw materials and their availability, their fluctuation in price, the effect of fuel costs and the efficiency of the furnaces, and the fluctuations of the steel prices are discussed at length.—T.G.

Development of the lining technique of open-hearth furnaces in North America L. Hütter (*Stahl Eisen*, 1960, **80,** June 9, 788–796) The author reports his impressions of a visit to the USA steel works in which he studied the latest lining techniques for basic OH furnaces, with particular emphasis on roof construction. The increased use of O_2 in refining imposes much higher stresses on the lining, particularly on the roof, but modifications of the doghouse and the roof achieved service lives comparable with those before the introduction of O_2 into the refining process.—T.G.

Oxygen and natural gas used in open hearth furnaces G. F. Chub (*Stal'*, 1960, (5), 426) A note from Zaporozhstal'. Testing with O_2 and natural gas fed into additional burners is reported. Melt time was reduced 16% and production increased 25% with 10·5% higher O_2 consumption and more rapid wear of the lining. **Study of furnaces working on natural gas instead of coke-oven blast-furnace gas mixture** (426) Methane was self-carburetted with natural gas soot. Better S removal was obtained. **A study of the working of individual OH furnace and mixer components and tests on new refractory materials** (426) High density chrome–magnesite brick was tested in furnace roofs, also other types of materials. The numbers of heats withstood are given. A new roof design was used on one furnace. **Longer lives for O.H. furnace tapping troughs** (426) Rammed linings were used.

Filming fuel oil flames in O.H. furnaces V. G. Lisienko, N. I. Korakev, and S. G. Troib (*Izvest. VUZ Chern. Met.*, 1959, (8), 127–134) Rapid filming makes it possible to study the structure and other characteristics of the turbulent hot flame in OH furnaces. In the cases described the flame consists of continuously pulsating vortices. The turbulence of the flame changes along the length of the furnace and is determined by the mode of combustion of the fuel and by the operation of the ports. According to the intensity of the fuel combustion the flame has a zone of intensive combustion and a zone where the combustion has been completed. The length of the intensive combustion zone of the gasified fuel oil in the flame has approximately the length of the zone with the stoichiometric concentration of the atomized fuel oil.

The development of the Maerz Boelens furnace F. Bartu (**Brochure from Maertz Ofenbau AG*, 1959, June) A description of the design features and operating data of Maertz Boelens furnaces constructed and converted since a previous report (*Stahl Eisen*, 1956, **76,** 152–158). Particular reference is made to the segmental method of construction, which facilitates repairs and shortens shutdown times.

Electric-arc furnaces J. Ravenscroft (*Iron Coal Trades Rev.*, 1960, **180,** April 29, 955–957) An account of the automatic control system to predetermined programme developed by BISRA (Automatic Power Input Control).

Programming and automatic control of electric arc furnaces (*BISRA Summary*, 153, pp.3) An account of the APIC equipment developed by the Association.

Electric smelting furnaces J. Astier (*Techn. Mod.*, 1960, **52,** April, 187–193) The furnace in most widespread use at present is the low-shaft or Tysland-Hole furnace. A detailed account of these furnaces is given, many of which have been made by the Elektrokemisk Company together with raw materials required, economic data relating to fuel and electrode consumption, labour costs, and a comparison with blast-furnaces. Finally recent improvements involving the use of self-fluxing agglomerates and preheated or prereduced charges are described.

Recent advances in steelmaking practices at Watertown Arsenal J. Zotos (*Foundry*, 1960, **88,** March, 108–112) Development work carried out in a basic electric-arc furnace, acid and basic induction furnaces and a vacuum basic induction furnace is described. It has clarified the necessity of minimizing P and S contents in cast low-alloy steels to obtain maximum ductility and toughness at low, medium, and high-strength levels and has indicated that a further improvement may result through the use of vacuum melting and casting techniques.—D.L.C.P.

New developments in the total automation of arc furnaces Yu. E. Efroimovich, V. M. Vinogradov, A. F. Kablukovskii, N. I. Shutkin, N. I. Gorbatov, and T. I. Zuev (*Metallurg*, 1959, (12), 13–16) A description of the structural improvement in the elenemts of an arc furnace, of new control devices, the working out of the suitable heat and technological conditions of the melt etc. Although these improvements are still at the first stage, results already attained have improved working conditions and give great promise.

Calderon charging H. M. Parker (*AIMME, Proc. OH Comm.*, 1959, **42,** 308–310) In an attempt to alleviate the congestion problem at Butler works of Armco Steel Corp., the Calderon charging method is used in which scrap is delivered to the furnace in bulk rather than in small lots. The system uses scrap cars and the Calderon 'scrap orientor', a specially designed hopper mounted on a bogey.—G.F.

Use of Prolerized scrap W. F. Mott and E. W. Brooks (*AIMME Proc. OH Comm.*, 1959, **42,** 302–306) Scrap specially prepared by the Proler cleaning process is in regular use in electric furnace melting at the Houston plant of Armco Steel Corp. It has resulted in higher melting yields, lower sulphur contents, and lower residual copper contents.—G.F.

Considerations on the principles of high intensity feeding of electric reduction furnaces S. Bokszcanin (*J. Four Electr.*, 1960, (1), 27–29) Rules for the control of electric reduction furnaces are analysed and discussed, stress being laid upon simplicity of design and construction, with the object of economical and full utilization of the transformers.—S.H.-S.

Speeding up the electric melting of 18KhNVA steel from alloy scrap F. P. Edneral, I. Kh. Kutuev, and R. I. Kolyasnikova (*Stal'*, 1960, (5), 428–433) Tests using scrap alloy instead of low-C iron in the charge and Si–Mn, M–Si–Al, or Mn–Si–Ca alloys as deoxidizers were carried out in an arc furnace. The O_2 blowing schedules are also given and the C removal giving optimum melting rate was examined. Removal of Cr, N_2, O_2, and S was also followed. Data for the trial heats are given and the properties of the ingots and rolled samples are shown.

Results obtained with inductive stirring in arc furnaces B. Hanas (*Tetsu to Hagane*, 1959, **45,** Dec., 1374–1382) A review of practice in several countries.—K.E.J.

Rational ingot mould and feeder head designs developed for killed steels G. F. Chub (*Stal'*, 1960, (5), 426) A note from Zaporozhstal'. A changed hot top section with increased taper reduced discard by 2%. The height of circular inserts was reduced from 190 to 120 mm.

Big end down ingot moulds boost alloy steel yield R. B. Shaw (*Steel*, 1960, **146,** March 20, 92–94). **Sideboards supply extra heat to boost ingot yields** G. J. McManus (*Iron Age*, 1960, **185,** March 24, 90–91) The use of 'Soffels Thermotomic Sideboards' in ingot moulds for stainless and other alloy steels is described. The slabs of material are hung in the top of the moulds before pouring. It has been found that with this technique ingots can be poured with the big end down. The cavity is less severe than with hot-tops, and an increased yield of 5% has been obtained. Big-end-down operation gives considerable advantages and ingots produced have been free from voids. In one series of tests, sideboard costs have been $1·5/t of steel compared with $1·2 for brick hot tops.—D.L.C.P.

Pressure poured billets: shortcut for steelmakers Griffin Wheel Co. (*Steel*, 1960, **146,** March 7, 90–93) The method of 'pressure pouring' steel is described; it has been used in the manufacture of train wheels, and other applications are considered. In this method, air pressure forces liquid metal from a ladle up a refractory tube into a graphite mould; when full the mould is plugged and removed. Stainless steel, carbon steel alloys, and boron steels have been cast into slabs, billets, and tube rounds. Intermediate steps are avoided and products are clean and to a close tolerance. Development work is continuing.—D.L.C.P.

Large rimmed ingots H. L. Farling (*AIMME, Proc. OH Comm.*, 1959, **42,** 101–102) The Cleveland plant of Republic Steel Corp. producing rimming steel slab ingots of 34 × 58 × 90 in. Brief details are given of some of the problems encountered in the development of this practice.—G.F.

Chemically capped steel J. S. McNairn (*AIMME, Proc. OH Comm.*, 1959, **42,** 85–90) The author discusses the suitability of chemically capped steel for deep-drawing cold-rolled sheet. Graphs are presented showing the reduced segregation when compared to fully rimmed ingots, and an extra slab yield of 2% is obtained with the capped ingots. The capping procedure used at the Dearborn plant of Ford Motor Co. is described.—G.F.

Use of low-carbon mechanically capped ingots for cold-rolled drawing-quality sheet J. F. Jarrell and V. H. Bridgewood (*AIMME, Proc. OH Comm.*, 1959, **42,** 94–97) Mechanically capped ingots at Steel Co. of Canada Ltd. give a slab yield about 3% higher than fully rimmed steel and 1½–2% higher than chemically capped steel. The capping practice is described, and typical properties and uses of the steel are discussed.—G.F.

Theory and practice of the deoxidation of steel N. N. Dobrokhotov (*Izvest. VUZ Chern. Met.*, 1959, (10), 23–28) The low m.p. products of the deoxidation are 'ferrophile', i.e. they are well wetted by the liquid steel and therefore slowly float up in it. The high m.p. products of the deoxidation are 'ferrophobe', i.e. not wetted by the liquid steel, and therefore coagulate and float up rapidly. The deoxidation of steel by large quantities of Al results in a reduction of the 'endogeneous' microscopic inclusions. This steel must be poured rapidly into moulds to avoid formation of crusts on the surface of the metal and therefore contamination by 'oxogeneous' inclusions.

Bottom pouring of killed steel without freezing S. I. Malyshev, Sh. P. Sakvarelidze, Z. A. Chkheideze, and K. K. Lolua (*Stal'*, 1960, (5), 419–420) Rapid pouring gave many defective ingots and slower pouring gave defects of a different kind. Superheating in the furnace with rapid pouring was more successful. Addition of graphite powder removes the oxide skin. Instead of lunkerite a mixture of coke and fireclay was used successfully.

Pressure treatment up-grades teeming ladle nozzles G. M. Carvlin jun. (*Iron Age*, 1960, **185,** Feb. 25, 68–70) The preparation and use of tar-impregnated teeming nozzles is described. Impregnation is by a vacuum-pressure process. Advantages accrue from reduced erosion of the nozzle, and better controlled pour, higher quality ingots with less intrusions and cleaner shut off. Cost saving per t of steel may be appreciable.—D.L.C.P.

Steel teeming technology improved G. F. Chub (*Stal'*, 1960, (5), 426) A note from Zaporozhstal'. Two-runner stools have been developed reducing the energy of metal flow and so the incidence of defects. Coke breeze and lime was not a successful substitute for lunkerite. **Increase in the life of two-ingot stools for bottom pouring of rimming steel** (427) Thickness had to be increased to prevent crushing, keeping the weight the same (20 t) by reducing the width. **A technology developed for melting and tapping semi-killed steel** (426) A note from Zaporozhstal'. 0·5–0·6 kg/t 45%Fe–Si and 0·5 kg/t Al is used. Modifications are noted.

A study of hot-topping practice D. V. Roloff and K. V. Smith (*AIMME, Proc. OH Comm.*, 1959, **42,** 18–29) The authors describe an experimental programme carried out at Gary Steel Works of United States Steel Corp. to evaluate methods of improving the hot-topping efficiency on 23 in. wide-end-up ingots. Sectioned ingot heads show the necessity for efficient top covers, for minimizing heat absorbed by the hot-top lining, and for allowing sufficient time for ingot solidification before the hot-top is stripped. Finally, the importance of careful maintenance of hot-tops, good teeming practice, and cars in rolling-mill discord practice, is stressed.—G.F.

Deoxidation of rimming steel ingot top regions G. F. Chub (*Stal'*, 1960, (5), 426) A note from Zaporozhstal'. Use of granulated 45%Fe–Si had various advantages. **Type 08 kp rimming steel melted with reduced ladle sample manganese content** (427) A note from Zaporozhstal'. Tests with reduced amounts of Fe–Mn gave poor results. **Quality of rimming steel with increased copper content** (427) The above 08 kp steel contained Co derived from pyrites cinder in the charge. Notes on other steels and casting conditions, composition, and properties are added.

High speed cobalt casting steel V. A. Kashchuk (*Izvest. VUZ Chern. Met.*, 1959, (8), 113–115) Pouring high speed cobalt steel into chill moulds ensures hardening. With a cobalt content exceeding 18% a dendritic structure forms after casting. Co increases the quantity of residual austenite in the quenching of the steel. On the strength of this investigation, the use of R 18 steel with up to 18%Co is recommended for high speed cast tools and components.

Pouring ingots with a covered shrinkage cavity A. V. Vishnyakov (*Izvest. VUZ Chern. Met.*, 1959, (9), 47–52) Tests are described of pouring ingots so as to form covered shrinkage cavities, insulated from the air so that these may later be sealed up by hot rolling. Various methods of casting have been tested, all without hot tops, and suggestions are made which have resulted in an improvement in ingot quality.

Quality of steel and the technical and economic production indices with the different methods of pouring A. N. Morozov and I. A. Stroganov (*Izvest. VUZ Chern. Met.* 1959 (10) 169–180) A comparison of the quality indices from the large metallurgical plants with the pouring of steel from the top and uphill does not supply sufficient data for the differences in the output of sound rolled material per ton of ingot and for the value of rejects as determined by the methods of pouring. With furnace cleaning the increase in labour costs for preparing the ingots poured uphill does not compensate for the lower labour costs for cleaning blanks. On the whole labour costs per ingot cast uphill and rolled are greater by 0·25–0·40 man-hours and therefore from the point of view of productivity casting from the top is important.

The effect of the manner of introducing aluminium on the quality of furnace steel I. E. Brainin and N. V. Gubenko (*Izvest. VUZ Chern. Met.* 1959 (10) 89–98) The investigations reported have shown that the introduc-

tion of Al into the ladle by tubes filled with the molten element did not bring about any appreciable changes in the macro- and microstructures of the steel. Only the quantity of oxides was slightly reduced. The original and the resulting grains, after tempering at between 850 and 1050° of steels with 0·8 to 0·5 kg Al/t introduced molten in tubes, were larger than when the Al was introduced in pieces at the rate of 1 kg Al/t.

Continuous casting. The process and its problems (*Anvil*, 1960, **5,** Spring, 28–29) A brief description is given of the development of the continuous casting process and its application in various parts of the world. Davy United's participation as steelplant makers is referred to. Diagrammatic illustrations of two types of continuous casting machines are given.

Continuous casting of steel in two strands at the works of Barrow Steel Ltd K. Heck (*Mét. Constr. Mécan.*, 1959, **91,** Oct., 717, 718, 721, 723) A description of the design and operation of the installation is given.

Continuous casting at Terni. Results achieved and future plans M. Signora and R. Cardano (*Met. Ital.*, 1960, **52,** May, 245–253) A description is given of the continuous casting plant at Terni which has a capacity of 150000 t/year and casts 60 t at a time. Present production is 5000 t/month of 140×140 mm billets. The necessity of speeding up steelmaking operation to suit the new process and of operation at maximum capacity is emphasized.

Nozzles for uniform spraying of water in continuous casting machines M. Yu. Brovman, E. V. Surin, and V. S. Litvinov (*Stal'*, 1960, (5), 416–419) The system in use at Krasnoe Sormovo is described and plans of the nozzle are given. Trials of various designs and the conditions for satisfactory operation are set out.

Study on continuous casting of steel. I. Primary cooling in continuous casting Y. Aketa, K. Sasaki, and K. Ushijima (*Tetsu to Hagane*, 1959, **45,** Dec., 1341–1345) With billets of mainly square type, the corner radius of the mould affects the longitudinal surface cracks, unevenness of primary cooling induces longitudinal surface cracks, and too high a casting temp. has the same effect; these effects are as for normal casting. Casting speed does not affect the billets, except that too high a speed induces longitudinal cracks in round billets (17 refs).—K.E.J

Study of the initial stages of the solidification of the metal in the moulds E. N. Ushakov (*Izvest. VUZ Chern. Met.*, 1959, (8), 31–38) The speed of the advancing front of crystallization in the initial stages is different from that of the following stage. During the filling of the mould a lesser quantity of metal solidifies in the initial period than is given by theoretical calculation based on the heat conditions of the process. The forced motion of the metal prevents the growth by the hard shell because of the intensive influx of heat from the crystallization front and because of the mechanical destruction by the moving mass of metal. The initial stage of the ingot formation affects the solidification of the deeper layers.

Elimination of gases during the solidification of 18 t ingots L. B. Kosterev and G. N. Oiks (*Izvest. VUZ Chern. Met.*, 1959, (9), 61–72) The volume of gases given off during the solidification of an 18 t ingot varies between 0·12 to 0·20 m^3/t. The volume per t of gases eliminated does not depend on the weight of the ingot but on the oxygen content of the steel. Rimming steels give off carbon oxides (90–95%) preferentially. In semi-killed steels this gas is accompanied by appreciable quantities of H_2. In killed steels it is mostly H_2.

Method of studying the chemical nonuniformity of the steel ingot S. Ya. Skoblo (*Izvest. VUZ Chern. Met.*, 1959, (10), 181–183) A sampling method is recommended for drilling a large number of test samples along the radius and the axis of one-half of an ingot. For a 20 t ingot the distance between the sample borings should be 50–100 mm and for smaller ingots of 15–20 t less than 50 mm.

The effect of manganese content in steel on the absorption of hydrogen when casting into moulds Yu. A. Nekhendzi and V. P. Kalenov (*Izvest. VUZ Chern. Met.*, 1959, (8), 123–126) Mn in steel causes increased H_2 absorption when casting into green sand moulds. The absolute and relative volumes of H_2 escaping from steel kept at room temp. decreases with increasing casting temp. and depends on the Mn content. In a steel with 0·3–0·4%C, the relative volume of H_2 eliminated during a storage of seven days increases initially (with up to 5%Mn) and then diminishes. With more than 10%Mn H_2 elimination ceases altogether, obviously owing to the formation of the austenite structure. In liquid steels also, H_2 content increases with the Mn content.

Properties and characteristics of basic brick for open hearth roofs W. S. Debenham (*AIMME, Proc. OH Comm.*, 1959, **42,** 126–134) The author describes the two major categories of basic roof design and examines the theory that there is some critical skewback pressure above which no growth can occur. He discusses the mechanical demands made on the basic bricks and considers the question of their chemical composition. Finally, further improvements still required in roof bricks are outlined.—G.F.

Protection of open-hearth roofs by an auxiliary jet J. V. Edwards (*JISI*, 1960, **196,** Nov., 289–294) [This issue].

Conversion to 70 per cent natural gas utilizing a continuous oxygen and combustibles analyzer G. M. Hagenberger (*AIMME, Proc. OH Comm.*, 1959, **42,** 4–16) A 70-t acid tilting OH furnace at Standard Steel Works of Baldwin-Lima-Hamilton Corp. has recently been converted from liquid fuel firing to 70% natural gas with 30% liquid fuel. The preliminary considerations are outlined, and details are given of the equipment for supplying and controlling the natural gas, and of the design of the combination burner. Simultaneously with the conversion, a continuous O_2 and combustibles analyser was installed; the advantages of this equipment are shown. The operating procedure of the furnace is described and the results from the first campaign show increased tonnage rate, lower fuel costs, and more heats per campaign.—G.F.

A practical program for the control of open hearth chemistry T. D. Hess and R. L. Kimberly (*AIMME, Proc. OH Comm.* 1959, **42,** 73–82) The authors describe the steps taken at Youngstown Sheet and Tube Co. to reduce the number of heats which are outside C and Mn specification. C is controlled by varying firing and ore-feeding rates according to simultaneous carbometer tests and temp. measurements taken throughout the heat. Mn varies because of variation in heat rise, incorrect calculation of the addition, and variation in recovery. The methods of achieving closer standardization of these factors are discussed.

The effect of shortening the period of pure boil in the basic open-hearth furnace on the quality of the steel A. Bichler (*Hutn Listy*, 1960, **15,** (2), 101–109) A detailed analysis is made on the basis of data obtained in works experiments in the Anshan Steelworks, China. The experiments showed that with adequate superheat, i.e. about 100°C, the period of pure boil in a 225-t furnace producing steel for heavy rails may be reduced to 25 min. without an increase of the gas and impurity contents or a deterioration of mechanical properties.—P.F.

A study of the influence of bath deoxidation on cleanliness of 1030 steel K. R. Mattson and R. W. Joseph (*AIMME, Proc. OH Comm.*, 1959, **42,** 104–118) To investigate the widely held opinion that bath Fe–Mn additions are essential to promote steel cleanliness, a series of fully killed heats of 1030 steel was made in which half the heats had no bath addition of Mn prior to the block. The heats were compared from the points of view of steelmaking practice, analysis control, Mn recovery, size and concentration of inclusions, and customer performance. The only significant effect noted was that elimination of the bath addition increased Mn recovery from 69·7% to 82·7%.

Open hearth combustion and its control A. Hogg and C. Holden (*Iron Steel*, 1960, **33,** May, 191–196) Burner design is discussed under the three main classifications of pressure jets, mechanical atomizers, and twin fluid atomizers. The theory of high momentum burners is considered, and instrumentation and control are discussed (25 refs).

Interaction of the carbon from the metallic bath with the bottom of the basic hearth of the O.H. furnace V. A. Startsev and P. V. Umrikhin (*Izvest. VUZ Chern. Met.*, 1959, (9), 53–59) A series of tests are described and optimum measures proposed to reduce reaction between the surface layer of the bottom of the furnace with the metal in the bath, among which are intensification of the oxidation of carbon in the metal bath during the course of the melt, alternating the melts of high alloy with those of low alloy steels and the speeding up of bottom repairs by fettling with magnesite dust with a thin layer of scale 100–300 mm thick.

The aerodynamics of open-hearth furnace regenerators C. Hulse (*JISI*, 1960, **196,** Nov., 264–274) [This issue].

Investigating the kinetics of the interaction between metal and slag by polarization with alternating current Yu. P. Nikitin and O. A. Esin (*Izvest. VUZ Chern. Met.*, 1959, (9), 3–14) The method here explained is suitable for studying the Fe^{2+} ion exchange between a liquid iron alloy with carbon (~4·3%C) and a slag containing CaO, SiO_2, and Al_2O_3 with the necessary FeO addition. The diffusion coefficient of the Fe^{2+} ions in the slag is of the same order as that established by means of the radioactive ^{59}Fe isotope. The natural rate of ion exchange between slag and iron is small, amounting to about 10^{-6} gram ion through 1 cm^2/sec with 0·9%FeO in the slag and it changes with temp. obeying the Arrhenius law. The activation energy of the migration of ions in the metal is 20 kcal/gram atom and in the slag 27.

Recent trends in the automatic control of open-hearth furnaces M. Gottwald, R. Klika, and L. Tomis (*Hutn. Listy*, **15,** (2), 85–96) The problem of automating OH furnaces fully is discussed, with special reference to development and requirements specific to Czechoslovakia. Various projects, some developed in the USSR for consideration in Czechoslovakia, are analysed. Control circuits of Czechoslovak development, and others used or projected abroad, are discussed in considerable detail, and the various special features are evaluated.

Melting trials in electric and open-hearth furnaces with ferrous material produced by a direct reduction process O. Masi and P. Cannizzo (*Met. Ital.*, 1960, **52,** May, 228) Cold metal burdens were used in electric and OH furnaces which contained from 20–50% of a ferrous material called 'P'. At each level of concentration of 'P' the average differences found in the hourly furnace production specific consumption and in the composition and characteristics of the final products obtained from certain heats are summarized. These differences were found to be mainly due to the presence of ferrous oxide in 'P'. Conclusions are drawn as to the suitability for use of such material.

Intensification of the steel melting processes by blowing powdered slag-forming substances on to the bath of the OH furnace V. M. Lupeiko and P. V. Umrihkin (*Izvest. VUZ Chern. Met.*, 1959, (10), 29–41) This method consists essentially in blowing the materials used for the formation of the slag directly on to the metallic bath in the form of dust. Experiments have shown that the temp. of the bath increases in spite of the cooling effect of such materials. The possibility has been proved of rapid slag formation and of a speeding up of the elimination of impurities from the metal. Further investigations are needed, but meanwhile it is possible to assert that it will play an important role in the OLP process of steel production in converters.

Some features of the chromium-containing slags of the melting down period in the basic O.H. furnace process A. L. Klein, V. A. Startsev, and P. V. Umrikhin (*Izvest. VUZ Chern. Met.* 1959, (8), 45–53) The presence of bivalent Cr has been confirmed in the basic Cr-containing OH furnace slags during the period of melting. The effect of the macroheterogeneous slag on the formation of chromium spinel and on the oxidation of the Cr from the metallic baths has been shown. For a Cr-containing burden it is advisable to use low m.p. fluxes such as highly basic agglomerates or limestone briquettes. The slag will then be more homogeneous and less

chromium spinel will form. Since this substance also forms in the oxidizing atmosphere at the slag-gas interface, it is advisable to reduce to a minimum the air excess during the period of melting.

Frothing of O.H. furnace slags M. Ya. Medzhibozhskii and E. I. Korochkin (*Izvest. VUZ Chern. Met.*, 1959, (8), 39–44) In agreement with experimental data and theoretical analysis, effective measures for reducing frothing of slags must ensure conditions for high temp. operation, good luminosity and flatness of the flame, synchronization between the increase in the basicity of the slag with the rise in temp. (especially during the melt-down period) to avoid high viscosity maintenance of the proper thickness of the slag cover at every stage of the heat etc.

Electricity supply to large electric-arc furnaces A. Haddock (*J. Jun. Inst. Eng.*, 1960, **70,** April, 191–201) The sort of current and variations encountered are shown and the effects of fluctuation in demand on the supply system are discussed. The need for minimizing these fluctuations is pointed out.

Sulphide capacities of silicate melts: I K. P. Abraham, M. W. Davies, and F. D. Richardson (*JISI*, 1960, **196,** Nov., 309–312) [This issue].

Sulphide capacities of silicate melts: II K. P. Abraham and F. D. Richardson (*JISI*, 1960, **196,** Nov., 313–317) [This issue].

Relation between quality of mild rimming steels and their oxygen content A. M. Pochtman (*Izvest. VUZ Chern. Met.*, 1959, (6), 31–36) The optimum oxygen content for mild rimming steels was obtained experimentally. It improves all property indices, the micro and macro structures of the metal, reduces separation into layers and contamination by non-metallic inclusions. The experiments revealed the necessity for working out efficient methods for the deoxidation of rimming steels.

PRODUCTION OF FERRO-ALLOYS

Mechanised charging of furnaces for production of ferro-alloys V. M. Grebenik, Ya. V. Dashevskii, L. D. Sokolov, and V. A. Sharapov (*Nauchnye Doklady Vyssh. Shkoly–Metallurgiya*, 1959, Jan.–March, 68–72) A machine is described with a rotating metal pipe 350 mm dia. and 3500 mm long when extended and mounted on rails is described. Its capacity was 120–220 kg/min. It revolves 35–45 times per min and discharge ceases when rotation stops.

Production of carbon-free ferro-alloys by alumino-thermic reaction (*Nat. Met. Lab., Ann. Rep.*, 1958–59, 25) The resulting carbon-free, ferro-chrome analysis was Cr 69·2, Fe 22·95, Si 3·73, Al 0·5, and S and P trace. The Fe–Ti contained 52%Ti.

Technical and economic efficiency of blast furnace production of ferrosilicon with oxygen M. I. Kolosov and M. M. Pischikov (*Izvest. VUZ Chern. Met.*, 1959, (6), 155–160) Tests at the Chelyabinsk Metallurgical Works have shown that the use of O_2 has resulted in an increase in the productivity of the furnace by 17·8% with a reduction of production costs by 25·81 rbls/t and in an increase in capital expenditure of 54·85 rbls/t, which, however, is recovered within 2·12 years.

Production of blast furnace ferrosilicon with oxygen-enriched blast Yu. A. Popov, E. A. Gamayunov, and A. T. Filippov (*Metallurg.*, 1959, (12), 3–6) The conclusions reached on the strength of experimental findings are that each additional percent of oxygen up to 25% increased productivity of the furnace by 4·0–4·5%, and reduced coke consumption by 0·9 to 1·5%/t of iron. With a content of O_2 in the blast of 25% the rate of the direct reduction of iron decreased from 50–55 to 37–48%. The Si was reduced in the furnace principally in the region above the level of the tuyeres. By increasing the O_2 content in the blast up to 25% the temp. of the flue gases is slightly reduced and the heat utilization coefficient increased from 0·54 to 0·62.

Utilization studies on chromite from Selad Creek, Calif. W. L. Hunter and G. V. Sullivan (*US Bur. Mines, Rep. Invest.*, 5576, 1960, pp.37) Successful concentration, ferro-alloy, and electro-smelting trials were carried out. (The alloy produced has no commercial application and was produced with high power consumption and excessive Cr losses in the large volume of slag.)

Savings through exothermic ferrocolumbium T. W. Merrill (*J. Met.*, 1960, **12,** May, 405) Disadvantages of FeCb—slow solution in steel, high density, oxidation in contact with oxidizing slag or high-temp. atmospheres, and consequent low recovery, led to the development of an exothermic alloy by Vanadium Corp. of America. The alloy contains $NaNO_3$ and FeSi, reacts quickly, and yields of 90–97% or better were obtained.

FOUNDRY PRACTICE

Steel Founders Society promotes casting applications J. C. Miske (*Foundry*, 1960, **88,** March, 136–137) A booklet issued as part of the US foundry industry market development programme is reviewed. Many applications for steel castings are described and illustrated.—D.L.C.P.

'Flow' design for castings puts metal where it should be Eimco Corp. (*Steel*, 1960, **146,** March 21, 156–160) The method of designing castings for a range of tractors is described. The 'unitized stress flow' concept involves studying the location and distribution of stresses to be encountered and designing castings to match. Results include reduced weight, resistance to fatigue, lower costs, fewer parts.

The effect of the quality of the original irons on the properties of castings B. P. Sergievskii and A. Ya. Khrapov (*Izvest. VUZ Vhern. Met.*, 1959, (9), 141–144) Exhaustive tests have shown that charcoal and coke-melted irons produced in different blast-furnaces of different origins show hardly any difference either in gas content or in mechanical properties. There is therefore no necessity for charcoal melted pig irons in the charge, the more so as these are generally dearer than the coke melted irons.

Penetration of metals with low melting point into moulding sand K. Fursund (26 *Congreso Internacional de Fundicion, IV Asamblea General del Instituto del Hiero y del Acero, Madrid*, 1959, pp.24, ref.C1) [In English] In order to investigate penetration phenomena without the high temp. changes associated with iron and steel, experiments were carried out with Sn–Bi alloys, in such a way that sand penetration could be observed through a glass wall. It is concluded that penetration takes place according to the same physical laws as with iron and steel; penetration is stepwise, and there is a considerable temp. difference between the sand and the penetrating metal. **Observations on internal tearing in steel castings** I. Minkoff, C. W. Briggs, and H. F. Taylor (pp.6, ref.C2) [In English] It is shown on parts of square and rectangular section and for rings and cylinders that cross-sectional stresses play an important part in determining tearing behaviour, especially in the presence of shrinkage cavities. Particular attention is directed to stress systems due to temp. distribution in the section of castings and their intensification by inadequate feeding. **X-Ray cinematography, using an image intensifier, of the flow of metals in shell moulds** K. Shobayashi and K. Okamoto (pp.6, ref.C6) [In English] Some details of the technique and the results obtained are given, including films showing the occurrence of blowholes and slag inclusions. 16 and 8 mm films were used. **Gases in cast iron: degassing tests under vacuum** S. Gallo and G. d'Alessandro (pp.12, ref.C7) [In French] Tests on grey and malleable cast irons degassed at pressures down to 0·5 mm Hg indicate that O_2 promotes the formation of shrinkage cavities, while H_2 and N_2 stabilize the carbides and cause the formation of hard spots and mottled areas. In annealing, degassing greatly accelerates carbide decomposition and lowers the temp. at which it commences. Micro-porosity and blowhole formation is eliminated by degassing (19 refs). **Graphitisation of nodular cast iron during annealing** (pp.15, ref.C8) [In German] Processes taking place in nodular cast iron quenched after heating to various temp. between 22 and 710°C, particular attention being paid to secondary graphitization. Austempering, normalizing, deformation, and low-temp. preheating treatments were also carried out to determine the influence of structure on secondary graphitization. Structural defects and their relation to the formation mechanism for graphite nuclei, and it is shown that these defects have a decisive influence on both nucleation and growth (32 refs). **Vacuum casting of grey iron** O. Nečas and R. Kamenský (pp.14, ref.C9) [In German] A report is given of work on the experimental laboratory-scale vacuum scale casting of grey iron carried out in Czechoslovakia by Viktkóvice Klement Gottwald Steel Works. Comparative tests, carried out by casting half the cast at atmospheric pressure and the remainder under vacuum, showed that the tensile strength of the vacuum cast grey iron was decreased by about 70%, and its hardness by about 13%. This was attributed to the fact that the treated iron possessed a higher proportion of ferrite and undercooled graphite. Bending tests showed that cracks formed in vacuum-castings run principally through areas with undercooled graphite (42 refs). **Mechanism of the formation of subcutaneous blowholes in cast steel** J. Pribyl and O. Starosta (pp.12, ref.C10) [In German] CO resulting from the C reaction is considered to be the cause of these blowholes. The effect is associated with decomposition of water vapour from the mould; oxidation of molten Fe at the casting surface; the C reaction and inoculation of blowholes by the CO produced; and diffusion of H in the blowholes and their consequent growth. The kinetics of the processes are discussed, and remedial measure suggested (23 refs). **Porosity in cast steel** O. Heide (pp.20, ref.C13) [Abstracts only, in all 4 languages] Factors influencing porosity in carbon steel casts in bentonite sands or Cronin shells were examined, porosity being measured in terms of H_2 content. The test pieces used, and method of sampling and analysis of H_2 content are described. H_2 absorption in the mould increased from 0·5 cm^3 H_2/100 g at 1610°C to 9·8 cm^3 H_2/100 g at 1710°C. A relationship was observed between porosity and final H_2 and porosity and Si or Si+Al content (26 refs). **The effect of free and combined magnesium on the formation of graphite in cast iron** D. Pohl, E. Roos, and E. Scheil (pp.15, ref.C14) [In German] A method was developed to distinguish between free and combined Mg. It is shown that the influence of Mg on surface tension depends up to a maximum on the lowering of S content formation of spherulites does not occur until both free and combined Mg are present. Mg is necessary for the formation of nodular graphite, both indirectly by combining with elements such as P, and directly. It does accumulate in the graphite, but remains mainly in the matrix. **A brief review of Belgian research on the correlation 'massiveness physical properties' of grey cast iron** A. de Sy and J. van Eeghem (pp.12, ref.C15) [In French] The results of a statistical study of a large-scale investigation carried out in conjunction with Belgian plants is presented. **Solidification and crystallisation problems in the manufacture of steel castings** B. Matuschka (pp.9, ref.C16) [In German] Crystallization and shrinkage mechanisms in chill and sand moulds are reviewed, shrinkage in steel sand and steel die castings is compared, and macro-pipe formation in steel ingots and castings is compared. **Ferro-alloys and inoculants for the production of high strength grey cast iron** H. H. Wilder (pp.7, ref.C17) [In English] Examples of American inoculation practice for 30000–45000 lb/sq. in. grey iron are given, together with tables showing compositions of inoculants strengths of typical alloy cast irons, and the effects of alloying additions on structure and hardness. **Manufacture of high duty iron** N. G. Chakrabarti (pp.6, ref. C18) [In English] A general review, with a note on Indian practice. **A study of hot tearing in steel castings** K. Beckius, M. C. Flemings, and H. F. Taylor (pp.14, ref. C20) [In English] A method is described for testing the influence of various factors on the susceptibility of steel castings to hot tearing. Sand strength, steel composition, and pouring temp. were investigated, and the influence of design was examined. It is concluded that internal and open external tears can be eliminated by designing to provide adequate feeding. **Behaviour of moulding materials during sudden heating, in connection**

with the formation of scabs H. G. Levelink (pp.14, ref.C21) [In German] The behaviour of dried clay-bonded sands and of oil-bonded sands during rapid heating was investigated by inserting test pieces in a furnace heated to 1400°C. The formation of a thin skin of sand, and its tendency to fracture are related to the formation of scabs. **Role of the size and quality of coke in the working of a cupola** R. Loison, L. Soubrier, and M. Decrop (pp.12, ref.C22) [In French] Two series of trials were carried out in two cupolas to determine the quality of coke best suited for cupola operation. The results are reported in detail. **Fundamental and practical hydrodynamic study of multiple feeder systems in sand casting** M. Jeanceolas, G. Cohen de Lara, and H. Hanf (pp.28, ref.C24) [In French] A review of modern theoretical knowledge of hydrodynamics is followed by a practical section, giving the results of a number of flow tests using plexiglass models, and describing an experimental method used for alloys cast in sand moulds. **Solidification of centrifugally cast tubes made from flake graphitic and nodular cast iron** H. A. Nipper (pp.18, ref.C26) [In German] The main factors influencing the solidification process are considered, namely those affecting the behaviour of iron, those related to the ingot mould and the factors connected with operating practice. **Refining pig iron with oxygen and powdered lime** B. Trentini, P. Vayssiere, J. Français, and M. Allard (pp.13, ref.C27) [In French] A report of three processes developed by IRSID, and results obtained. The processes are: the OLP converter process, the use of powdered lime injected with pure oxygen in open-hearth refining, and pre-refining pig iron in the ladle using the same principle. **The angle of friction in green moulding sands and its relationship to technological properties and hydration of clays** J. Navarro-Alcacer (pp.14, ref.C29) [In Spanish] The concept of 'internal friction angle' derived from Mohr's circle theory is introduced, and its use proposed for the explanation of the flowability of moulding sands. Variation of permeability in terms of changing flowability is also investigated (23 refs). **Influence of gating on the cost of the metal used in a casting** D. E. Civis (pp.7, ref.C30) [In Spanish] A graphical method of determining costs is described. **Results of trials on nodular cast irons inoculated with Cu–Si–Mg alloys** F. Rodriguez-Yufera and J. Orland (pp.31, ref.C31) [In Spanish] It is shown that the mechanical properties of nodular cast iron made with these inoculants are homogeneous, and good values for rotary bending fatigue strength and Young's modulus is obtained. Some applications of the material are described. It is concluded that Cu can be used satisfactorily instead of Ni for inoculation. **Contribution to the study of the factors which improve the Young's modulus of cast iron** A. S Amat (pp.13, ref.C32) [In Spanish] The influence of rate of cooling, composition, the addition of inoculants and other factors on the modulus of elasticity is examined.

Lectures on the mechanised foundry No.12 (*Fonderia Ital.*, 1960, **9,** (4), 193–198) Various types of plant are described including foundries for various types of castings, large mechanized foundries for mass production of small and medium green sand castings and other types.

An ultramodern foundry plant A. Kugler and F. Eisermann (*Gjuteriet*, 1959, **49,** (10), 261–262, 265–266, 269–270, 273–274) A description of the layout, equipment, and operation of the foundry plant and machining shop erected by Sulzer Bros. at Oberwinterthur, Switzerland.

Some aspects of present South African foundry practice J. Steele (*Brit. Found.*, 1960, **53,** April, 154–161) The materials and methods of South African jobbing foundries and the variety of castings produced are described.

Stacking frames feed castings through production stages L. Pudup (*Iron Age*, 1960, **185,** April 21, 150–151) The use of stacking-frames for transferring throttle-body castings between automatic machining stations is described. The frames hold vertical stacks of the castings and are filled automatically from below; after being latched on to the machines the castings are automatically withdrawn as required.

Cupola developments (Third Report) Sub-Committee TS 43 (*Brit. Found.*, 1960, **53,** March, 93–107) The performance of nine recently installed hot-blast cupolas is summarized. Water cooling is discussed and its effect in reducing refractory consumption, maintaining a constant melting zone and in bringing about consistent operation are revealed by a study of the operating characteristics of ~30 cupolas. Slag-metal reactions in the basic cupola are reviewed.—A.D.H.

Flames and furnaces: The science of furnace construction M. W. Thring (*Iron Steel*, 1960, **33,** May, 197–201) Problems of refractory wear in melting furnaces and the testing of refractories are reviewed, and their availability and manufacture are discussed briefly, with an account of the composition and properties of aluminosilicate refractories.

The uncooled basic cupola B. R. Douglas (*Brit. Found.*, 1960, **53,** Feb., 74–78) The modification of an acid 32in. cupola for operation with a basic lining without hot blast or water cooling enables charges containing up to 70% of steel to be melted. The product is suitable for the production of SG iron.—A.D.H.

An analysis of cupola operator performance A. A. Timmins (*BCIRA, J. Res. Dev.*, 1960, **8,** March, 247–265) In the course of visits to 400 foundries the BCIRA Foundry Operations Section has accumulated much information on the use of labour in cupola operation. This information has been analysed and is presented in tabular and graphical form. Standards are put forward by which comparisons of performance may be made. The application of the results of this research to improvements in layout and equipment is also considered.

New hot-blast equipment for cupolas in small and medium size foundries E. R. Becker (*Gjuteriet*, 1959, **49,** (10), 277–278, 281; abstracted from *Giesserei Praxis*, 1959, (8)) This article gives a description and illustrations of various recuperator systems suitable for small and medium plants.

Calcium carbide as an addition to the cupola charge R. Chudzikiewicz, T. Kukula, and J. Birkenfeld (*Prz. Odlewn.*, 1960, **10,** (3), 78–81) In East Germany a special low melting-point carbide is used as a charge addition. In Poland, since the special carbide is not available, ordinary welding carbide has been tried. This did not give the advantages which, according to the literature, were obtained using the special carbide.

Refractory linings for cupola furnaces (*Fond. Ital.*, 1960, **9,** (5), 231–240) The construction and operation of the cupola furnace and the various types of refractory linings used (acid and basic) are described together with the maintenance carried out after individual melts. Finally there is a brief description of refractory ramming and internal brickwork.

Research into the desulphurisation of cupola cast iron with sodium carbonate T. Dumitrescu, S. Stefanescu, and N. Iatan (*Met. Constr. Masini*, 1959, (5), 361–366) Based on experiments in the laboratory and under conditions of production it may be concluded that the optimum duration of desulphurization with Na_2CO_3 is 8–10 min for small quantities of cast iron (80–100 kg) and between 10 and 25 min for large (3000–5000 kg). The optimum proportion of Na_2CO_3 is 0·5–1·0%. The degree of desulphurization is greater with a larger initial sulphur content Precautions must be taken to avoid the cupola slag getting into contact with the basic sodium carbonate slag.

Investigating the combustion zone in a cupola with a single row of tuyeres of box type or with slits A. A. Anan'in and V. P. Chernobrovkin (*Izvest. VUZ Chern. Met.*, 1959, (10), 139–145) Quantitative data have been obtained regarding the non-uniformity of fuel combustion in the cupola, conditioned by the shape and number of tuyeres. Box-like tuyeres cause the air blast to enter the cupola as isolated streams bringing insufficient air supply to the space between the tuyeres and causing the boundary of the oxygen consumption to reach lower levels and to producing a lower maximum temp. Tuyeres with slits level out the boundaries of the combustion zone in the peripheral regions of the stack and thus raise the maximum temp.

Use of the low frequency induction furnace with pouring channel in ferrous metal foundries E. Calamari (*Fonderia Ital.*, 1960, **9,** 183–192) After a brief summary classifying the various types of induction furnaces the article explains why the use of the low-frequency induction furnace should be extended. The production of special quality iron and alloy steels in these furnaces is described. Finally a table is given which summarizes the technical data relating to induction furnaces including low frequency furnaces showing the superiority of the latter.

Low frequency A.S.E.A. furnaces without magnetic cores B. Hanas (*J. Four. Electr.*, 1960, Jan.–Feb., 39–42; from *ASEA Rev.*) The construction and operation of coreless LF furnaces are described and compared with those of HF induction furnaces.

The effect of moisture on molten cast iron N. Kayama, T. Ishino, and K. Saito (*Waseda Univ., Rep. Casting Res. Lab.*, 1958, (9), Nov., 15–20) [In English] The experimental work included blowing air of various moisture contents on to iron at various temp., and the effect of blowing moist air through coke. More steam exists in the cupola than had been thought, probably arising from the coke and furnace wall Moisture in the blast thus increases oxidation of metal in the melt-down zone, and produces deleterious effects, e.g. increase of chilling and formation of shrinkage cavities —K.E.J.

Change of characteristics of molten iron treated with calcium silicide by keeping in the molten state M. Maruyama and M. Ito (*Imono*, 1960, **32,** Feb., 108–113) Although characteristics of molten iron treated with calcium silicide were changed by keeping in a molten state, Si, S, and O_2 contents did not show any marked change. Carbon and residual Ca contents however tended to decrease and it was concluded that these determined the changes in the characteristics of the molten iron. The primary cause of spheroidizing of graphite was thought not to be the supercooling but the purification of molten iron which caused the supercooling.

The formation mechanism of internal white cast iron Ya. N. Malinochka (*Izvest. AN, SSSR, OTN, Metallurg. i Topl.*, 1959, (6), 92–101) A compact white central core of a casting is possible when the liquid iron, overheated above the temp. of the eutectic equilibrium, maintains itself at that high temp. right up to the start of the rapid cooling of the last liquid portion at the core of the casting. This may be expected with a rapid rate of cooling. Under such conditions a great temp. difference will be maintained across the crystallization front.

Distribution of manganese and nickel between the phases of white cast iron I. E. Lev (*Metalloved. Term. Obra. Met.*, 1959, (12), 44–47) A direct analysis of cementite and ferrite has shown that Mn is concentrated to a large extent in cementite and Ni in the matrix. An increase in the rate of cooling of white cast iron components results in rendering uniform the distribution of Mn and Ni between phases. With a sufficiently rapid rate of cooling the Mn and Ni atoms have no time to concentrate in their corresponding phases. An isothermal holding at 680° increases the non-uniformity of the Mn and Ni distribution between the phases of white cast iron.

Influence of sulphur on the strength and hardness of high-duty grey cast iron J. V. White (*4th Annual Meeting, Inst. del Hierro y del Acero*, 1959, ref.A23, pp.11) [In Spanish] Particular attention is paid to the effect of low S contents, and the results of a series of tests are reported on a high-duty grey iron. It is concluded that S must be kept between 0·095 and 0·180%, other factors being kept constant, to obtain the required mechanical properties and eliminated hard spots.

The casting of grey iron, before the introduction of the new materials and methods of manufacture. III D. Iturrioz (*Met. y Electr.*, 1960, **24,** April, 89–97) A summary of present methods of production in Great Britain, Sweden, Germany, and USA.—S.H.–S.

Study on high-strength cast iron. III. On the various properties of high-strength cast iron made by oxygen blowing I. Iitaka and K. Nakamura (*Waseda Univ., Rep. Casting Res. Lab.*, 1958, (9), Nov., 21–23) [In English]

High-strength iron produced by oxygen blowing has properties almost identical with those of iron produced from steel scrap, but with a tendency to superiority in tensile strength, vol. of growth, wear resistance, and response to inoculation.—K.E.J.

Some experiments on the properties of ferritic blackheart malleable cast iron C. T. Moore (*Brit. Found.*, 1960, **53,** March, 107–120) The effect of the Si, P, and C contents respectively on the mechanical properties of ferritic blackheart was determined. The strength was improved by raising the Si and P contents and by lowering the carbon content. An increase in Si and P contents leads to an increase in the transition temp. range of notched bar brittle failure. Water quenching from 650°C followed by tempering at 350°C eliminated brittle failure and increased the strength still further. The utility of the bend test in assessing skin quality was also demonstrated.—A.D.H.

The shaking ladle in the desulphurization and alloying of cast iron melts S. Tunder (*Mét. Const. Méc.*, 1960, **92,** May, 317–328) Equipment for accelerating metallurgical reactions and ensuring close contact between lime and cast iron by means of a shaking ladle at the Mannesmann–Mear Iron Works is described. The mechanism of desulphurization and the applications and advantages of the process are shown.—S.H.–S.

Whiteheart malleable iron. Some physical and metallurgical factors D. Magri (*Fond. Ital.*, 1960, **9,** (5), 219–230) A description is given of the production of whiteheart malleable iron showing the influence of the various chemical elements on foundry properties and on decarburization and graphitization and of the process of annealing in a controlled atmosphere. Finally, the foundry finishing operations are described and the properties and use of white malleable iron are briefly summarized.

Properties of pearlitic malleable irons (*Met. Des. Eng.*, 1960, **51,** March, 105–109) Latest data on pearlitic malleable irons, adapted from the *Malleable Iron Castings Handbook*, just published, are described.—S.H.–S.

Pearlitic malleable iron C. F. Joseph (*Brit. Found.*, 1960, **53,** Feb., 58–67) The production and applications are described of pearlitic malleable (ArmaSteel) in the automobile industry. The material possesses higher machinability than steels of comparable strength.—A.D.H.

The partitioning of alloying elements in malleable irons G. Sandoz (*NRL Report No.*5268, 1959, Feb., *PB* 151413, pp.26) The partitioning of a number of alloying elements between the cementite and austenite phases during first-stage graphitization has been determined. V, Cr Mo, and Mn (not combined with S) concentrate in the cementite phase, together with small amounts of Si, Cu, Ni, Co, and Al. The mechanism is discussed (32 refs).

Production trials of nodular cast iron C. Bradaschia (*Bol. ABM*, 1960, **16,** Jan., 123–138) Preliminary tests and pilot trials of nodular cast iron production are reported. Synthetic sand (sea sand and zirconia in a 1:1 ratio) is used to give the best surface finish, a small basic-lined cupola was used and the iron ladle-desulphurized with a mixture of rare-earth carbonates, the cupola blast was oxygen enriched. It was shown that the process was applicable to both hypo- and hypereutectic irons and that the products were uniform and responsive to heat treatment.—P.S.

Spheroidal-graphite types of Ni-resist austenitic cast iron A. B. Everest and O. Nickel (*Found. Trade J.*, 1960, **108,** April 28, 515–522) Irons with 2·4–3%C, 20–36%Ni, and up to 5·5%Cr and sometimes Si and Mn are discussed with their heat-treatment, machinability, and weldability. Strength, especially at high temp., wear, and corrosion resistances are also noted. Uses are also considered.

Calcium spheroidal graphite cast iron T. Kusakawa (*Imono*, 1959, **31,** May, 509–520) A study has been made of the properties of Ca and the additional elements Ce and Mg in order to determine the characteristics of Ca as an additive metal. The conclusions are: (1) both Ca and Mg have little solubility in iron but have appreciable vapour pressures; (2) Ce has similar physical properties to Ca but higher specific gravity. The problem of the solubility of Ce in iron remains when powdered Ca–Si coated with Ce compounds is applied, spheroidal graphite cast iron with the tensile properties of 40 kg/mm² or more can be obtained. This process has been developed on an industrial scale.

On titanium cast iron with a eutectic graphite structure M. Sawamura (*Imono*, 1959, **31,** May, 486–508) The author has invented a process for manufacturing Ti iron castings with a eutectic graphite structure. This paper describes various characteristics and uses of Ti cast iron and the application of the process on an industrial scale. Finally the reasons for the production of the eutectic graphite structure in the Ti cast iron are discussed in the light of experimental results.

The production of castings in permanent molds G. M. Carr–Harris (*Canad. Min. Met., Bull.*, 1960, **53,** April, 275–280) A brief review with a large selected bibliography (85 refs).

Drying and heating foundry ladles: why gas wins G. Holmes and K. G. Rhodes (*Ind. Gas*, 1960, **23,** June, 22–27) An account of investigations leading to a successful process and installations for ladle relining using gas burners for heating.

On the results of using olivine sand for moulding materials K. Kobayashi (*Imono*, 1959, **31,** July, 674–682) [In Japanese].

On permeability in sand moulds M. Mutaguchi (*Imono*, 1959, **31,** July, 660–666) Certain defects arise in castings due to the permeability of the sand mould. In this paper the author studies a method of measuring the permeability of the sand mould directly. This consists of determining the permeability from the equilibrium pressure in the mould cavity on the introduction of gas at a constant rate. The location of the gas escape was confirmed by smoke mixed with the gas in the mould cavity.

When, where and why do defects occur in synthetic sand moulds? Y. Harada and K. Nishiyama (*Imono*, 1959, **31,** July, 667–673) The conclusions of the investigations are as follows: (1) The scab and rat tail in synthetic sand moulds occur at the places where expansion of the mould surface is concentrated and deformation takes place. (2) The more the hot compressive strength increases the greater is the strain on the mould surface and the likelihood of scab and rat tail occurring. (3) Vapour pressure also breaks the mould surface: when this is higher than the metal pressure an A-scab will become a B-scab. (4) most of the scabs in synthetic sand moulds occur toward the inside. (5) The result of the expansion test of foundry sand showed that shock-heated expansion is more liable to cause defects than free expansion.

Method of preparation of synthetic sands for cast irons V. Lo Re (*Bol. ABM*, 1960, **16,** Jan., 177–185) An account is given of the equipment, materials, and method of preparation of sand mixes at the Instituto de Pesquisas Technologicas. The mixes, of which details are given, form a sound basis for development work.

Sand testing and moulding properties A. Mal (*Fond. Belge*, 1960, **30,** June, 175–179) This article discusses the limitations and importance of the green strength test, the difficulty of measuring sand deformation and the desirability of controlling foundry sand by both shatter and green strength tests. The author concludes by forecasting the future development of the use of castings in the light of developments in their manufacturing techniques and consumption possibilities.

A new factor for control of moulding sands. The pH J. Castells Ruiz (*Inst. Hierro Acero*, 1960, **8,** Jan., Special Number, 60–75; *Fond. Belge*, 1960, **30,** June, 167–174) The reasons for the appearance of spongy-like surface defects in grey iron and steel castings, which have been found when old moulding sands are used, are discussed. The sands which produce these surface defects are always old ones with an acid reaction and the control and adjustment of pH is suggested as a remedy.—P.S.

Moulding sands with glycol additions, particularly for heavy-metal casting E. Brunhuber and W. Büchen (*Giesserei.*, 1960, **47,** June 30, 358–361) The present experiments were all made with non-ferrous metals but the good results obtained suggest their use for ferrous metals also. The authors described the properties of the glycols and their price; the glycols can be mixed with water in any proportion, the reduction of the water content of the moulding sand is of great advantage in casting as less water vapour is present to react with the molten metal. The castings (non-ferrous) showed a smoother surface when glycol was added to the sand.—T.G.

Moldability of moulding sand. V. Moore's flowability K. Murata (*Rep. Gov. Ind. Res. Inst., Nagoya*, 1955, **4,** June, 251–257) [In Japanese].

An instrument for testing the strength of moulding sands K. Réti and P. Németh (*Koh. Lapok-Öntöde*, 1959, **10,** Sept., 217–218) An hydraulic instrument for testing the compressive strength of moulding sands is described.

Load deformation curve of moulding sand. II K. Futaki, K. Murata, and T. Yoshihara (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1955, **4,** July, 309–312) [In Japanese].

Grain sizing of moulding sands. V. Variation of grain distribution in fineness test K. Hashimoto (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1955, **4,** (12), 529–536) [In Japanese].

The angle of friction in green moulding sands and its relation to technological properties and the hydration of clays J. Navarro-Alcaver (*Inst. Hierro Acero*, 1960, **8,** Jan., Special Number, 1015) The concept of flowability is discussed and methods for its measurement are reviewed together with the theory of the hydration and bonding action of clay minerals. The theory of Mohr circles is applied to the study of internal friction in moulding sands as a measure of flowability and the index $1/\phi$, the inverse of the angle of friction, has been found to give a numerical assessment of flowability. Curves for $1/\phi$ as a function of shear strength or permeability are plotted for a variety of sand mixes. It is shown that it is possible, for a chosen value of $1/\phi$, to obtain mechanical strengths that are functions of the clay and moisture content or, for a given strength, the clay content to give the desired flowability can be established. It is confirmed that in the quartz–clay–water system of green moulding sands that are well mixed and properly rammed, the quartz is the element that is conveyed by the deformations of the water–clay network surrounding it to produce the specific surface form (23 refs).—P.S.

A novel automatic core-sand preparation plant K. Bandow and R. Ritter (*Giesserei.*, 1960, **47,** June 30, 362–364) The plant is intended for the small or medium-size foundry, it prepares 10 t of sand per h. The incoming sand is dried in a kiln and then stored in hoppers, from these it is distributed after binders and water have been added automatically.—T.G.

Preliminary tests on the use of a sand-slinger for the production of castings in synthetic sand A. Hoffmann and R. Engel (*Giesserei.*, 1960, **47,** July 14, 378–385) The importance of sand composition and its compressive strength on satisfactory working of a sand-slinger are pointed out. Correct mode of filling the mould is another point mentioned. Observing these points the sand-slinger proved very useful in increasing the productivity.—T.G.

The degassing of ferrous alloys in fine foundry work P. Destables (*Mét. Const. Méc.*, 1960, **92** May, 335–343) Technological considerations on the industrial degassing of alloys are discussed and physical removal by rabbling, dispersion, or precipitation. Control of gas content of metal, methods of chemical determination of alloys in ferrous metals and of O_2 in steel by the Gotta method are described.—S.H.–S.

Cast iron for linings of combustion engine cylinders J. Bradík (*Slévarenství*, 1960, **7,** (3), 103–110) Researches designed to improve the wear resistance of the linings are reported. Small additions of Cr, V, and Ti are beneficial. Mechanical properties, but not the resistance to wear, are improved by blowing N_2 or argon through the molten metal, and by inoculating the melt with $CaCN_2$.—P.F.

The technology of casting blade wheels for hydraulic gears J. Kadlec and V. Šimana

(*Slévárenství*, 1960, **8**, (3), 73–77) The casting of gears, mostly light alloy, used in hydraulic transmissions of Diesel railway engines is described. For high transmission efficiency, high-quality surfaces must be obtained on complex castings. Urea resin cores are used.

Castings made of high-tensile (magnesium) iron. (In conjunction with the Zaporozhe Machine Construction Institute) G. F. Chub (*Stal'*, 1960, (5), 427) A method of treating iron in the cupola forehearth with Si–Mg alloy is mentioned with an estimate of costs.

Fundamentals of the manufacturing process of calcium-treated S-G iron and effects of the combined addition of calcium and cerium T. Kusakawa (*Waseda Univ., Rep. Casting Res. Lab.*, 1958, (9), Nov., 11–14) [In English] The effects of Ca addition were clarified by studies of the fundamental properties of Ca, Mg, and Ce as additives. To produce fully spheroidal graphitic iron, it is suggested that Ca and Ce be added in combination.—K.E.J.

Structural changes in ferritic magnesium cast iron A. I. Yatsenko (*Metalloved. Term. Obra. Met.*, 1959, (12), 47–50) The most noticeable change in the material investigated takes place at the grain boundaries when heating up to 500°. This corresponds to the temp. interval for low impact strengths in Mg irons. A rapid transition through this critical region and holding at higher temp. (when the dispersive carbides at the grain boundaries disappear) may be an effective means of preventing a drop in impact strength.

The structure and hardness of surface-hardened s.g. graphite M. M. Klimochkin (*Metalloved. Term. Obra Met.*, 1959, (12), 39–43) The maximum hardness of ferritic cast irons is obtained by quenching from high temp. but it still remains below that from quenching pearlitic cast irons from much lower temp. The hardness of a quenched surface after heating in a furnace is practically independent of the original structure of the cast iron. In components with pearlitic structure the hardened layer has a zone of high hardness and a transition zone to lower hardness.

Studies of the properties of indigenous foundry moulding materials (*Nat. Met. Lab., Ann. Rep.*, 1958–59, 6–7) Considerable progress has been made in assessing the moulding characteristics of Indian foundry sands and determining their suitability for various types of castings. The results of investigations carried out on 15 sand samples are summarized.

Moulding-sand practice in Australia H. A. Stephens (*Brit. Found.*, 1960, **53**, April, 161–177) The foundry sand resources of the Australian Stetes are surveyed, the availability of other moulding materials is, and sand practice and control are described.—A.D.H.

Basic properties of moulding mixtures and their effect on the surface quality of castings J. Dlezek (*Slévárenství*, 1960, **8**, (2), 65–72) On the basis of a literature survey and his own researches, the principles involved in choosing moulding mixtures giving best surface quality are discussed.—P.F.

Handling sand—325,000 tons a year (*Foundry*, 1960, **88**, March, 156–158) Arrangements for delivering sand to Ford Motor Co.'s foundry at Brookpark, Cleveland, are described. The sand is stored at the dockside, and transferred to the plant by bulldozer, grab-crane, and rail.—D.L.C.P.

Mechanize use of cold setting sand mixes Farrel-Birmingham Co. (*Foundry*, 1960, **88**, March, 103–107) Experiences of a foundry in preparing and using cold setting sand mixes are recounted. An automatic measuring and mixing system prepares the sand, iron oxide, sodium perborate, and oil binder materials. The sand is mostly used for making cores, but is economical for moulds in some cases. The saving in time, the practical elimination of ramming and bedding in, the reduced manpower, the reduction in rodding, and improved shakeout permitted by the process are factors which offset the relatively high cost of the special binder sand mixture.—D.L.C.P.

CO_2 moulding sand additive—casting finish improves shakeout D. L. Longeuville (*Foundry*, 1960, **88**, March, 189–194) Experience at a foundry using a glucose additive in the Na silicate–sand is described. An addition of 1 to 2% gives several advantages without unwanted side effects. Benefits are: better peel of sand from metal, cleaner castings, improved surface finish, easier shakeout.—D.L.C.P.

High temperature properties of CO_2 sand J. Kashima and H. Miyasaka (*Waseda Univ. Rep. Casting Res. Lab.*, 1958, (9), Nov., 41–47) [In English] For a silica sand containing a special Na silicate binder, data are given for high-temp. properties of strength, retained strength, expansion-contraction, and deformation, and the influence of additives. Coal-tar pitch and gilsonite are preferred additives.

The effect of CO_2-process sands on hot tearing J. M. Middleton (*Brit. Found.*, 1960, **53**, Feb., 67–74) A hot tear test casting is described which under controlled conditions is sensitive to variations in moulding material. CO_2 process moulds were no more prone to cause hot tearing than normal dry sands if conditions were controlled but wide variations in severity of hot tearing were obtained by different foundries carrying out the test. The density of the mould, milling procedure, and casting temp. are the most important variables.

The effect on a green sand of contamination by used CO_2-process sand J. M. Middleton (*Brit. Found.*, 1960, **53**, Feb., 53–57) Laboratory and works experiments have shown that deleterious effects will arise of green sand used for steel casting contains >12½% of CO_2-process sand. Green and dry strength and measurements of pH can be used to check the amount of contamination.—A.D.H.

Differential thermal analysis of olivine minerals products in Japan K. Kobayashi (*Imono*, 1960, **32**, Feb., 125–129) A study was made of the olivine minerals as a raw material for moulding sand using differential thermal analysis. The results were: (1) many differences on the curve between these minerals were found: (2) products of Hokkaido, Ehime, and Akita Prefecture showed a nearly linear curve on the differential thermal analysis curve and these were recognized as forsterite by X-ray analysis: (3) serpentine minerals change at 600–700°C in the differential thermal analysis curve and change to a forsterite crystalline structure after heating at 700°C: (4) it was found by measuring heating weight loss that the change at 600–700°C is due to dehydration of the mineral.

The use of peat in claybonded moulding sands W. B. Parkes (*BCIRA J. Res. Dev.*, 1960, **8**, March, 169–176) Tests made in the laboratory and on a large scale in foundries indicate that peat is a useful addition to green sand moulds. It is as effective as wood flour in preventing scabbing and has two imperant advantages; the addition of large amounts has a less harmful effect on moulding properties; dirt inclusions due to the friability of moulds which are air dried by standing before closing are less frequent. Only one size grade of peat is at present available and this cannot be used to replace all grades of coal dust without deterioration in surface finish.

From solid ceramic mould to refractory shell J. Doškář (*Slévárenství*, 1960, **8**, (2), 39–43) The scope and utilization of the standard 'lost wax' method, and shell-moulding are discussed.—P.F.

Versatile mould handling system boosts foundry flexibility (*Iron Age*, 1960, **185**, April 7, 100–101) The arrangement of a new system for handling moulds is described. The moulds are palletized and transported on roller tables and a transfer car. The system increases production per square foot of floor area, eliminates bottlenecks, and delays and cuts costs.—D.L.C.P.

Melting and stickle moulding of spiral chambers for hydraulic turbines V. G. Oliva (*26 Congreso Internacional de Fundicion, IV Asamblea General del Instituto del Hierro y del Acero, Madrid*, 1959, pp.6, ref.A2) [In Spanish] Details are given of an improved moulding technique which gives a better product at lower cost. **A new moulding sand control factor—the pH value** J. C. Ruiz (pp.13, ref.A7) [In Spanish] A description is given of the control of a scab defect appearing on grey iron and steel castings, by measuring the pH value of the sand mixture and adjusting the alkalinity by suitable additions. **The control of graphitisation in grey iron castings** J.-O. C. Oller (pp.10, ref.A11) [In Spanish] Some examples are given of the use of the chill test to control graphitization in high strength alloyed and unalloyed castings in a foundry, and it is concluded that the test is a reliable control method. **Foundry training** M. D. Saenz de Tejada (pp.5, ref.A13) [In Spanish] A general description, with some notes on specialized training, including safety aspects. **Quality control during casting** E. R. Pala (pp.7, ref.A14) [In Spanish] Variables determining mould properties are permeability, density, and moisture. Correlation curves were established between the first two properties and hardness for a range of moisture contents, and the curves used as a basis for quality control. **Study of some moulding sands in the Viscaya–Alava region** M. de la Granja Alonso (pp.34, ref.A18) [In Spanish] (46 refs). **Specification of nodular cast iron by thickness** A. A. Abaunza (pp.16, ref.A22) [In Spanish] Published work on the influence of thickness on the properties of castings made from nodular iron is reviewed, and a test programme to investigate the problem is described, in which a series of test pieces differing in 5 mm steps was tested for mechanical properties. Composition, and inoculation techniques, are discussed (13 refs). **Bainitic Cu–Mo–Cr cast irons** M. P. Roig (pp.14, ref.A31) Manufacture, mechanical properties, and microstructure of this series of irons are reviewed (13 refs). **Cupola refractory linings. Galdácano stone** A. Alonso-Urguijo Balzola (pp.10, ref.A32) [In Spanish] General problems connected with wear of basic cupola linings are discussed, and the properties are described of linings made from Galdácano stone, obtained in the Vizcaya province of Spain. **Classification test for defects in cast steel** J. Vazquez (pp.28, ref.A33) [In Spanish] Defects are classified according to their origin, and methods of prevention investigated in each case (34 refs). **A graphical solution for risering, using exothermic materials** C. San Jose Seigland (pp.8, ref.A44) [In Spanish] (17 refs). **Method of casting by the CO_2 process** E. P. Piu (pp.10, ref.A54) [In Spanish] The mechanism of the CO_2-sodium silicate reaction is discussed, and the method is described.

Service life of roofs of electric melting furnaces of different thicknesses M. N. Kaibecheva, N. A. Tulin, and N. I. Fadeeva (*Metallurg*, 1959, (12), 21–22) Three structural alternatives are described for furnace roofs in which the central section is thicker than the peripheral part. This construction has increased service life from 90–100 to 160–185 melts.

Feederheads in sand moulding F. Gaty (*Techn. Humanisme*, 1959–60, **57**, (1), 3–31) Trials are described and the mathematical theory is given and methods of calculation of dimensions are indicated.

Risering of ductile iron castings R. W. White (*Foundry*, 1960, **88**, March, 96–102) Freezing, shrinkage, and feeding distance characteristics of ductile iron are discussed in relation to risering requirements in dry and green sand moulds.—D.L.C.P.

The fundamentals of pouring technique J. Czikel (**Giesserei–Nachrichten*, 1956, Dec., 5–14) Methods of determining factors related to the pouring of iron and steel castings are investigated, including optimum pouring times and rates, and gating calculation. Nomograms are developed to determine pouring time and rate and solidification time.

Pouring castings in ungassed sodium silicate-bonded moulds W. G. Probst and G. R. Scott (*Foundry*, 1960, **88**, March, 82–85) A simple new method of obtaining a good finish on bronze, Babbitt, and grey iron castings is described and results from a foundry using it are reported. The method involves pouring into moulds faced with green sodium silicate-sand mixture. A finish of 125 microinches rms is obtained, compared with 600 with natural bonded sand. Other advantages have also been found in that mould uniformity, casting dimensions, quality, and output have been improved.—D.L.C.P.

Team of corn-base binders improves foundry cores N. Kowall and S. Hadyn (*Iron Age*, 1960, **185**, Jan. 28, 94–95) The advantages which a foundry gained by using corn-base binders for cores are described. 'Mogul', a corn cereal is used to obtain green strength and 'Dexocor' a corn sugar product for baked strength. Advantages over oil binders are

greater dimensional accuracy, better finish, reduced baking time, easier cleaning of equipment.—D.L.C.P.

Steelfoundry production developments D. Bennett (Brit. Found., 1960, **53,** Jan., 31–36) The applications of the CO_2 process, machine moulding, and exothermic materials to the production of high quality castings are described.—A.D.H.

Core baking by the dielectric method W. Nynkowski (*Prz. Odlewn.*, 1960, **10,** (3), 69–74) A dielectric baking plant introduced in Poland in 1958 has shown many advantages over the old type. It has the largest thermal efficiency, a short process time, a large coefficient of use of the auxiliary equipment and a wastage of only 5%. The application of this method is limited by the size and shape of the cores and requires the use of a suitable binder.

Mould drying Sub-Committee TS 39 (*Brit. Found.*, 1960, **53,** Jan., 41–48) Ramming density was found to have little effect on the rate of drying of clay bonded sand moulds. The general problem of the removal of moisture from moulds is discussed and methods of determining the moisture content of moulds are described. The water content and the temp. are the most important factors controlling drying.—A.D.H.

How new cast stainless alloy solves problem tasks E. A. Shaefer (*Iron Age*, 1960, **185,** March 10, 126–128) Properties of a new precipitation-hardening stainless alloy 'CD–4MCu' are described, and the first performance figures from the field are reported. The alloy can be cast into parts characterized by high strength and good corrosion resistance. Analysis is: 0·04% max. C; 1·0% max. Mn; 1·0% max. Si; 0·04% max. P; 0·04% max. S; 25–27%Cr; 4·75–6%Ni; 1·75–2·25%Mo; 2·75–3·25%Cu. The following properties are also notable; ductility after hardening; resistance to galling; machinability; weldability; ease of casting. The alloy has a two-phase austenite–ferrite structure in the as cast condition; sigma-phase appears in the fully hardened alloy as scattered particles in the ferrite matrix. Applications as impellers, liners, and pump values in difficult conditions have confirmed the value of the alloy.—D.L.C.P.

Precision casting of nitridable titanium steel T. Visi (*Per. Polytechn.*, 1959, **3,** (2), 163–168) [In German] The manufacture and nitriding of sewing machine parts from Ti-bearing steel is described.

Heat-resistant 12%-chromium steel castings [medium and large, for turbine construction] R. Schinn (**Vereinigung der Grosskesselbesitzer Mitteilungen*, 1958, (57), Dec., 397–406) The properties of cast 12%Cr steel for this purpose are reported, in so far as these differ from the properties of forged steel (due to lack of mechanical deformation and much larger holding times during heat treatment).

High temperature steel castings (*Stahl-Eisen Werkstoffblatt*, 471–60, fourth edn., March 1960, pp.6) The steels dealt with in this specification should all be scale-resistant to gases at temp. above 600°C, the steels are produced in the electric-arc furnace. In tables are listed: composition, mechanical and physical properties, scale-resistance and high-temp. applications, hot-working, and welding properties.—T.G.

Stainless steel castings (*Stahl-Eisen Werkstoffblatt*, 410–60, 3rd edn., March 1960, pp.6) This specification contains data concerning steels containing at least 12%Cr. All steels are produced in the arc furnace. In tables are listed: Composition, mechanical and physical properties, application of the steels, heat-treatment, and welding.—T.G.

Plastics in pattern making H. Schiegner (*Koh. Lapok-Öntöde*, 1959, **10,** Sept., 200–202) The author reports on the production and use of plastics in patternmaking in East Germany. These have resulted in 70% saving as compared to the production and use of metal patterns.—P.K.

Gating and feeding of large steel castings A. P. Riley (*Found. Trade J.*, 1960, **108,** April 21, 487–491) Important factors in gating and feeding are pointed out for the production of sound castings. Feeding in general and the use of exothermic compound and other methods of heating are briefly considered.

Choked gatings in iron casting B. V. Rabinovics (*Koh. Lapok-Öntöde*, 1959, **10,** Sept., 203–209; Oct., 232–243) The paper contains a comprehensive review of the design and use of choked gatings in iron casting in the Soviet Union.—P.K.

Automatic moulding devices H. Bergman (*Koh. Lapok-Öntöde*, 1959, **10,** Aug., 187–191) The author describes two automatic moulding devices used in the production of fittings in West-Germany.—P.K.

The effect of humidity on the mechanical resistance of sand cores for castings V. Lo Ré (*Bol. ABM*, 1960, **16,** Jan., 171–176) Tensile tests have been made on a series of test-pieces made from various core sand mixes. S. Vicente sand formed the basis for all these mixes. The tests were made on the stoved pieces after storage in air, in a humidity chamber or in moist sand for various times. All the mixes were found to be affected prejudicially by humidity, those most affected were the ones containing calcium lignosulphonate. Those containing linseed oil maintained the best strengths. It is pointed out that it is necessary to take the time and conditions of storage of stoved cores and moulds into account in the foundry.—P.S.

Mould materials J. Kashima (*Imono*, 1959, **31,** July, 635–636) [In Japanese] An essay.

Studies on the CO_2 process H. Miyasaka (*Imono*, 1959, **31,** July, 652–659) The results of experiments carried out to investigate the high temp. properties of CO_2 sand include: (1) above 500°C the hot strength of CO_2 sand decreases greatly down to less than 1 kg/cm$_2$ and the amount of deformation is also great, but no obvious change in hot strength is caused by changing the gassing time; (2) Contrary to (1), the retained strengths of the CO_2 sand specimens at temp. above 500°C show a great increase which seems to be the main cause of poor collapsibility. (3) To increase elevated temp. strength and decrease retained strength of the CO_2 sand about 2% of additives such as coal-tar pitch, gilsonite, and asphalt emulsions are recommended. Such additives have no adverse effect on the expansion/contraction characteristics of the CO_2 sand. (4) Bentonite or clay additions are not to be recommended in view of their decreasing the hot strength while increasing green and retained strengths of the CO_2 sand.

Hardening cores and moulds by the use of CO_2 gas. I. S. Tachibana, T. Yoshihara, K. Hashimoto, O. Toyoda, and W. Hashizume (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1955, **4,** Aug., 355–359) [In Japanese].

CO_2 process: meters and core making O. Gerstmann (*Giessereitech.*, 1960, **6,** May, 149–151) Two meters are described for admitting predetermined quantities of CO_2 into moulds, one is a simple time switch and the other an hydraulically operated valve. A core-making machine on the CO_2 principle is also described.

Castings and their importance in engineering F. Naumann (*Technik*, 1960, **15,** July, 463–470) The advantages of permanent-mould castings over sand castings for engineering parts are pointed out. The lost-wax process for precision parts in iron and steel is briefly mentioned and spheroidal graphite cast iron described. The author also remarks that modern methods should be used for eliminating the still existing discrepancy between demand and output of foundry products.—T.G.

Increased economy by the use of precision castings E. G. Nickel (**Industrie-Anzeiger*, 1960, **82,** May, 10) A review of the principles in the design and production of precision cast parts is given. Tolerances are discussed but it is pointed out that surfaces of working parts will in any case require some finishing treatment. Inspection standards must be adjusted to a level where reduced numbers of rejects is offset by cost of machining or other processes. Various parts are shown and a list of suitable materials is included.

Vertical centrifugal tube casting development A. A. Krystofik (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957; Oct; *PB* 151 308, pp.10) The development of a vertical centrifugal tube casting process for producing gun tubes is outlined and illustrated.

Application of investment castings to the manufacture of small arms components and related manufacturing problems J. F. Panda (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957; Oct.; *PB* 151 308, pp.19) The advantages and problems associated with the manufacture of investment-cast small arms components are related.—A.K.

Sintered alumina molds for investment casting F. C. Quigley (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957; Oct.; *PB* 151 308, pp.12) The manufacture of a thin-wall, high-strength mould which will withstand casting temp. in excess of 3000°F is reported.

Precoats for investment casting G. Pributsky and W. M. Kisner (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151 308, pp.9) Details are given of the development at a suitable precoat for investment casting which was much cheaper than the proprietary product previously used.—A.K.

Simplification of component manufacturing through precision casting and other methods E. R. Mackiewicz (*Proc. Ind. Tech. Conf. on Metals Processing*, 1957, 16–17–18, Oct.; *PB* 151 308, pp.11) The advantages of close tolerance casting techniques for producing components are stated. The casting of a tank sprocket and a crankshaft are discussed.—A.K.

Dimensional aspects of lost-wax investment casting R. Taylor and N. Mason (*Found. Trade J.*, 1960, **108,** June 2, 696–700) This article is concerned with the reasons why, although the lost wax investment casting process is often claimed to be accurate to ±0·005 in. this tolerance is sometimes not achieved. The reasons for the variation between an average casting dimension and the die cavity dimension are the wax contraction below the die cavity dimensions; the mould cavity expansion due to wax expansion on heating prior to melting out; the mould shrinkage on drying and its liquid binder and the shrinkage of gel films binding the refractory particles; the mould expansion due to high temp. firing (approx. 1000°C); and the shrinkage of the casting from the molten state to room temp.

Resinless shell moulding G. I. Gastnes (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151 308, pp.5) The resin shell moulding process and its disadvantages are outlined. Experiments using waterglass as a bond are described.—A.K.

Thermal decomposition of phenolic resin used for the shell moulding process K. Futaki, H. Ikegami, and T. Yoshiwara (*Rep. Ind. Res. Inst. Nagoya*, 1956, **5,** Jan., 8–12) Weight loss and gas evolved were measured. Most resins decompose ~500°C and the curves are hardly distinguishable. Cured resins decompose more slowly. Loss of wt. is roughly proportional to gas evolution.

The strength of shell moulds I. Szekeres (*Koh. Lapok-Öntöde*, 1959, **10,** Aug., 192–196) The effects of the amount of resin, thickness of shell, degree of baking, additions and treatment on the strength of shell moulds at room and casting temp. are discussed.

On the method of measurement in the shell mould. VI. Distortion in the hot state K. Hashimoto (*Rep. Gov. Ind. Res. Inst. Nagoya*, 1958, **7,** Feb., 110–116) Methods of measurement of distortion are recommended and it is shown to be due to insufficient curing of the resin.

Solidification problems in the production of steel castings B. Matuschka (*Radex Runds.*, 1960, June, (3), 128–138) The author studied the solidification phenomena of steel in sand moulds with particular emphasis on the similarities and dissimilarities with ingot moulds. The various forms of shrinkage and piping are considered. Recommendations are made for correct sand-moulding for steel castings and a few practical examples are discussed.—T.G.

The behaviour of moulding materials during rapid heating and the formation of scabs H. G. Levelink (*Giesserei.*, 1960, **47,** June 30, 339–346) Test-pieces of various shapes were formed from clay-bonded and oil-bonded sand and rapidly heated. The influence of the shape of the test pieces, the wall thickness, a dressing or wash, composition of the sand, moisture content, and type of binder on scab formation was studied. The author attempts to correlate the findings on the test pieces with defects occurring in actual moulds during casting.—T.G.

Study on resins for shell molding J. Kashima

(*Waseda Univ., Rep. Casting Res. Lab.*, 1958, (9), Nov., 35–39) [In English] To reduce the cost of resin powder, promising initial results were obtained with a monomer of a methylolurea methyl ether. Because of the low decomposition temp., however, it appears to be desirable to mix it with oxidized resin powder.—K.E.J.

Flow of metal into moulds Sub-Committee TS 35 (*Brit. Found.*, 1960, **53,** Jan., 15–20) A series of stills taken from a film describing the flow of metals into moulds when different types of ingates are used.—A.D.H.

The solidification of castings W. F. Chubb (*Castings*, 1960, **6,** Feb., 9, 11, 13, 15, 17, 19, 21, 23) The general mechanism of solidification of metals is outlined.

A study of the solidification process of magnesium-treated iron G. Ohira and K. Ikawa (*Brit. Found.*, 1960, **53,** Jan., 23–30) The process of graphite formation in Mg-treated Fe–C–Si alloys was studied by quenching samples during solidification. Four modes of separation occurred according to the carbon equivalent of the iron. The formation of quasi-flake graphite and ledeburite and the effect of inoculation by Fe–Si on these processes and on spheroidization were also investigated.—A.D.H.

Comments on 'A study of the solidification process of magnesium-treated iron by G. Ohira and K. Ikawa' H. Morrogh (*Brit. Found.*, 1960, **53,** Feb., 88–89) It is considered that the explanation of the solidification process is overcomplicated.—A.D.H.

The influence of vibration on the structure and improvement in mechanical properties of bronzes and of cast iron B. Iswayk and M. Labecki (*Prz. Odlewn.*, 1960, **10,** (3), 74–78) An apparatus was used in which an electromagnet introduced vibrations into solidifying metal. The following effects were observed: (*a*) a reduction of grain size; (*b*) and increase in the dispersion of lead in lead bronzes; (*c*) a refinement of graphite flakes in grey cast iron; (*d*) and increase in tensile strength.

The effect of vibration on stress relief of castings Sub-Committee TS 32 (*Brit. Found.*, 1960, **53,** Jan., 10–13) The vibration of a grid casting and of a stressed test piece failed to produce any reduction of stress except at high levels of stress when a very small relief occurred.

Some experiments concerning the as-cast grain size in 30% chromium cast irons J. Rickard (*BCIRA J. Res. Dev.*, 1960, **8,** March, 200–216) An investigation of some of the factors controlling as-cast grain size of 30%Cr cast irons is described. A fine grain size may be obtained by pouring these irons at low temp. or by additions of either Ti or N_2. The grain size may also be changed by vibrating the mould during casting. The influence of these grain-refining techniques on the tensile strength, hardness and microstructures of the irons has also been studied.

Investigating the emission of gases from moulding mixtures and cores at high temperatures L. Sofroni, E. Cohn, and C. Cosneanu (*Met. Constr. Masini*, 1959, (5), 367–373) The two types of moulding sand mostly used in Rumania are examined and also the binders, cellulose-pitch, sulphite liquor, glucose, linseed oil, Bakelite, etc. The elimination of gases is measured against time and graphs are appended.

Blast barrel automation cuts foundry cleaning costs (*Iron Age*, 1960, **185,** Feb. 18, 110–111) Advantages accruing in a foundry from the use of a 27 ft^3 automatic blast cleaning barrel are explained. The unit can require no operating labour, is fast, and has low maintenance cost.—D.L.C.P.

The effects of chemical composition on the residual stress formation in iron castings T. Owadano (*Imono*, 1960, **32** Feb., 114–119) The results of experiments using strain-hindering methods are as follows. 1. The process of residual stress formation in castings of white iron resembles that of grey cast iron but the stress formation in the former is much larger. This is due largely to the difference in Young's modulus. 2. On the basis of these experiments the stress-relaxation by plastic deformation is not detectable in white cast iron below the transformation temp. about 650°C being considered the 'critical temp.'. 3. Addition of Si to white pig iron decreases the residual stress as the Si content increases up to 3·8% but further increase up to 7% has no effect. 4. Increase in phosphorus content in grey cast iron only slightly increases the residual stress.

VACUUM METALLURGY

Vacuum melting and casting K. G. Lewis (*Iron Steel*, 1960, **33** May, 179–183) Improvements in tensile and impact properties due to vacuum treatment are discussed and several examples are given. Effects on creep properties, workability, and fabrication and other properties are considered (141 refs).

Structure of cast iron melted under reduced atmospheric pressure G. Ohira and K. Ikawa (*Imono*, 1960, **32,** Feb., 119–125) Experiments showed that the eutectic graphite structure in the cast iron containing Ti was due to the deoxidation of Ti. A further experiment was aimed at finding some difference between the obstructing action of S and Ti on the spheroidal graphite formation of the Mg-treated iron. It was found that in the Mg-treated iron containing sulphur the quasi-flake graphites were separated from the eutectic austenite cell while in the iron containing Ti the graphite formed in spheroidal austenite was of some irregular type, and very fine thread-like graphite was formed at the boundary of the austenite at the end of eutectic solidification.

Fundamental study on vacuum-melting of pure iron and stainless steel. I. On the crucible ingot formation and recovery of added elements H. Sawamura, T. Mori, M. Yakushiji, H. Inoue, and Z. Takao (*Tetsu to Hagane*, 1959, **45,** Dec., 1334–1341) Results are given for melting iron in four types of electro-magnesia crucible: one gave no contamination by oxygen after 2 h at 1600°C. Refining pure iron melts with H_2 led to H_2 in the metal. Oxygen content was controlled by immersing a graphite rod in the melt, but this rapidly increased the carbon content. Ingot practice was improved with a modified mould. Stainless steels were melted by adding Si and Mn under A at 20 mm pressure to prevent vaporization loss —K.E.J.

Vacuum melting of cast iron. I. Influence of vacuum melting on the structure and mechanical properties of cast iron I. Iitaka and M. Kikuchi (*Waseda Univ., Rep. Casting Res. Lab.*, 1958, (9), Nov., 1–10) [In English] Details are given of the vac melting and casting equipment, which deals with 450 gm specimens. The crucible used must not contain reducible oxides, but graphite is not entirely satisfactory. Results from Australian charcoal iron, BF iron, and Fe–C–Si show that the reaction austenite→graphite+ferrite is promoted by vac. melting, and the range of grey iron is extended to the hypoeutectoid region.

The DHHU process for vacuum treating molten steel F. Harders, H. Knuppel, and K. Brotzmann (*J. Met.*, 1960, **12,** May, 398–402) A description is given of the principle and operation of the Dortmund–Hoerder Hüttenunion process, in which the metal is transferred in portions from the casting ladle to a degassing chamber and recirculated to the remaining metal in the ladle. Properties of the treated steel are described. **Discussion, the DHHU process** E. A. March (404) Practice using this process at the Midland Works of the Crucible Steel Co. of America is discussed.

Degassing of steel by vacuum casting for the production of castings and forgings V. Scalise, A. De Negri, and V. Picardi (*Met. Ital.*, 1960, **52,** May, 237–244) Vacuum stream degassing almost completely solves the problem of defects caused by inclusions of gases, particularly H_2, in big forgings and castings. A general description of principles and methods is given. The plant and techniques used at the SIAC Genoa Cornigliano works are then outlined with reference to two methods used there—vacuum stream ingot degassing and vacuum ladle degassing.

The vacuum treatment of steels in the ladle K. G. Speith, H. von Ende, and A. Pfeiffer (*Stahl Eisen*, 1960, **80,** May 26, 737–744) The results of the vacuum treatment of arc-melted steels in 80-t ladles by immersing the ladles in vacuum chambers are reported. The pressure that was held for 10 min varied between 4 and 15 mm. The O levels were reduced from 0·020–0·030% usually to 0·002 with maxima of 0·010%. No deoxidants are later required in the moulds. The vacuum treatment had no effect on the N level, but H was reduced, the more the higher the original level. The vacuum treatment imposes a fall in temp. on the melt, this loss is the higher the stronger the melt boils (15 refs).—T.G.

The effect of the remelting of a heat-resistant alloy on a nickel base in a vacuum furnace on its properties V. A. Sheremet'ev (*Izvest. VUZ Chern. Met.*, 1959, (10), 43–48) It is possible to produce in the vacuum arc furnace ingots without surface blemishes. The volume of the pipe is greatly reduced and porosity, scabs, and surface defects eliminated. Remelting in the vacuum arc furnace reduces C, S, O, and N contents in the metal as well as the non-metallic inclusions. It improves long-term strength and plastic properties.

Industrial electrically heated furnaces and other equipment for heating F. Gerlach (*Elektro-Warme*, 1960, **18,** April, 119–131) An illustrated review of equipment marketed in Germany including an electron-beam melting furnace, and high-vacuum arc and induction furnaces. The review is followed by a list of manufacturers of the equipment described.

Vacuum annealing of wire K. H. Fritz and G. A. Michael (*Wire Wire Prod.*, 1959, **34,** Dec., 1607–1609, 1659, 1661) A new type of heat treating furnace for annealing wire is described. It is of German manufacture. The heating hood is fixed in an elevated position, and the annealing pots are run underneath and raised into position on a hydraulic ram. Thus the furnace can be well insulated, connexions need not be flexible, and a heavy crane is not necessary. The equipment can be used with protective atmosphere or vacuum.—D.L.C.P.

Modernization of the OKB-706 vacuum furnace for annealing special steels in a magnetic field M. N. Solov'ev and I. Z. Naumov (*Metalloved Term. Obra. Met.*, 1959, (11), 51–53) Suggestions are made to modernize this furnace by building in devices for producing a magnetic field during annealing at a pressure of 10^{-3} to 10^{-4} mm.

REHEATING FURNACES AND SOAKING PITS

The use of models in studies of the flow of fuel, and of the heating of soaking pits S. Černoch, I. Repiský, and M. Míček (*Hutnik*, 1960, **10,** (1), 21–24) Transparent aerodynamic models were used in studies of the optimum design, and number and disposition of burners. It was found that four short-flame burners should be better than the two long-flame burners used in rectangular soaking pits abroad. Full-scale tests with soaking pits designed according to the indications obtained from the models showed that the modified design was superior to the conventional one: fuel consumption decreased by about 25% compared with a conventional pit.—P.F.

Induction heating for forgings P. E. Hammarlund and Y. Sundberg (*Ing. e Indust.*, 1960, **27,** April, 70–77) Underlying principles of induction heating, and examples of its application to the induction heating of forgings are reviewed.

The electric resistance heating of steel W. Stich (*Stahl Eisen*, 1960, **80,** June 23, 891–892) Latest improvements in the direct resistance heating of blooms for rolling are reported. The main problem is still the resistance of the contacts with the blooms. The temp. in the interior of the blooms is higher than that of the surface, this is advantageous for the rolling process, it also permits rolling at lower temp. than when conventionally heated blooms are used.—T.G.

HEAT TREATMENT AND HEAT-TREATMENT FURNACES

Designing trays for roller hearth furnaces G. W. Wardwell (*Met. Prog.*, 1959, **76,** Dec., 81–83) Lightweight combined with strength, and ability to withstand severe stresses are among the requirements emphasized.

[Thermal] Inertia-less furnaces I. S. Nazarov (*Izvest. VUZ Chern. Met.*, 1959, (6), 83–91) It has been proved theoretically and demonstrated in practice that it is possible to construct furnaces with working spaces made of

metals with high reverberatory properties. The highest reflective properties have been found in polished surfaces of brass on a copper base and of Al. Furnaces with 'mirror' water-cooled metallic surfaces do not require time for heating and cooling. These inertia-less furnaces are more efficient from the heating point of view. Some experimental furnaces have been tested and results are tabulated.

Experience with the operation of the reconstructed three-zone continuous furnace V. N. Medvedev, N. I. Butenko, and V. P. Murovtsev (*Metallurg.*, 1959, (12), 28–31) The 'Giprostal' design is explained for a three-zone, furnace bottom heated for slabs up to 150×800×2000 mm fuelled by coke-oven and furnace gas of 2000 calorific value under 220 mm water gauge. The operation results in a fuel saving of 153 kg of fuel/t.

Heat treatment of commercial and alloy cast irons G. Ribet and P. G. Maceraud (*Ing. Mecc.*, 1960, **9,** May, 49–56) After having referred to the possibilities offered by heat treatment of cast iron to improve mechanical characteristics and general performance, the authors describe the principles on which this is based. An account is given of normal quenching, marquenching, and surface hardening. Finally, the results of tests and examples of castings subjected to heat treatment are given.

New heat treatments (*Machine Shop Mag.*, 1960, **21,** Feb., 70–71) An undisclosed method known as the Bassett Process is referred to, said to give greatly refined grain size and high strength.

Determining the optimum heat treatment for high manganese GI3L steel Ya. K. Alekseev and P. T. Khokhlov (*Metalloved. Term. Obra. Met.*, 1959, (9), 60–62) A description is given of the optimum heat treatment for mandrels made of this steel The tests were carried out in the plant heat treatment shop under normal conditions with the normal apparatus used for the production of this component in series A graph for the best heat treatment process has been constructed.

Shop peening and heat treatment for the half axles for trolley buses N. Ya. Vol'vak (*Metalloved. Term. Obra. Met.*, 1959, (11), 40–42) It has been found from practical experience that 40 Kh and 45 type steels may be used for half-axles with good results. After the introduction of a new schedule in 1958 for heat treatment followed by intense shot peening so as to obtain the maximum hardness fractures have been reduced to the lowest level.

Heat treatment of tools for the nut and bolt industry J. Garnier (*Draht*, 1959, **10,** Aug., 357–358) A range of tool steel compositions is given, and the heat treatment of plain C tool steels is described briefly.

High productivity in structural engineering. 2. Fabrication methods at the Cleveland Bridge & Engineering Co. Ltd D. M. Potter (*Weld. Met. Fabr.*, 1960, **28,** March, 106–109, 112) A review under seven headings: (*a*) shrinkage and distortion control; (*b*) temperature control; (*c*) standardization of joint design; (*d*) development practice; (*e*) instruction, distribution; (*f*) testing and inspection; (*g*) machine welding and tooling, with statistics of increased production efficiency.—S.H.–S.

Efficient heat treatment of rolls for hot rolling mills M. P. Braun, O. S. Kostyrko, E. P. Dobryanskaya, and A. I. Kondrashev (*Izvest. VUZ Chern. Met.*, 1959, (8), 105–112) An investigation of various schedules of heat treating large components of 55 Kh steel has shown that isothermal holding immediately after forging is of great advantage. The most effective heat treatment ensures successive recrystallization. The method suggested, combining anneal with normalization, shortens the operation by 40%. Hundreds of rolls have been so treated and have resulted in substantial savings.

Explosive hardening of steel proves out in field service W. A. Harper (*Iron Age*, 1960, **185,** Feb. 4, 85–88) The properties of Mn steel after velocity impact hardening (VIH) are described. Hardening is brought about by explosive shock waves. Advantages over pressing or hammering methods are: speed, treatment of irregular surfaces possible, casting flaws are revealed, less deformation of workpiece. A new sheet explosive is well suited to the work. Sound welds can be treated successfully, examples of application are drive-chains, railway track parts, crusher jaws, and cool cutters.—D.L.C.P.

New heat-treating process J. A. Edwards (*Iron Steel*, 1960, **33,** May, 184) A description is given of the main features of the Tricarb process, developed by Leeds and Northrop Co. of Philadelphia. This process can be used for homogeneous or controlled case carburizing, carbon restoration, heardening, or carbonitriding. The equipment is combined in a single compact unit, all stages are automatically controlled, and a temp. range of 790 to 1010°C and a carbon range of 0·15 to 1·15% are possible.

The influence of alloying elements on the first stage of tempering in high-carbon steels H. W. King and S. G. Glover (*JISI*, 1960, **196,** Nov., 281–287) [This issue].

Structural changes in steels and refractory alloys used in furnaces for gas carburising G. Pomey (*Rev. Mét. Mém. Sci.*, 1959, **56,** Oct., 471–483) Investigations of structural changes leading to service failure showed impoverishment of matrix in Cr during carburization, due to precipitation of carbides; this is enhanced near the surface, and during the oxidation period surface oxidation progressing to internal oxidation takes place.

Automatic hardening and tempering of carbine barrel forging (*Process Control Autom.*, 1960, **7** April, 174–175) A description is given of the design and operation of a fully automatic continuous hardening and tempering furnace for the treatment of carbine barrel forgings built by G. W. B. Furnaces Ltd., and installed at the Royal Ordnance Factory at Fazakerley.

The use of sylvinite for heating steel components when hardening A. Ya. Antyshev (*Metalloved. Term. Obra. Met.*, 1959, (9), 60) At the 'Kalibr' works the salt baths for hardening operate at 800–900° and consist of a mixture of 48–50%NaCl; 48%Na_2CO_3, and 2–4%NaCN. Sylvinite may replace the above mixture as it is cheaper, but all components heated between 840–860° in sylvinite, when cooled in oil, assumed an oxide film. It was found that by substituting NaOH for sylvinite to the extent of 20% and adding 2–4%NaCN as a deoxidizer the components showed a perfectly clean surface.

Determination of the depth of hardening in induction hardening G. Seulen and H. Geisel (*Werkstattstechn.*, 1960, **50** May, 263–268) Studies on the factors affecting the depth of hardening in induction hardening showed that the depth of hardening depends, at constant hardening temp., constant frequency and equal quenching conditions, directly on the power input, the dia. of the sample and the nature of the material to be hardened. Diagrams for determining the power needed for a required depth of hardening are developed.

Nitriding D. Flament (*Mét. Constr. Mécan.*, 1959, **91,** 725–727, 729, 730) The principles and practice of nitriding are outlined, with an account of the influence of Cr and Al additions, the compositions of nitriding steels, and a note on Chapmanization, nitriding under pressure, and ionitration.

Accelerated nitriding F. Barbas (*Usine Nouv.*, 1960, May, Special No., 111–113, 115–117, 119, 121, 123) Steel and other metals under extreme pressure conditions and methods of furnace nitriding, and a comparison of ordinary and accelerated methods and the properties of the materials obtained are discussed in detail.

The nitriding of ferrochrome H. Zak and Z. Kulinski (*Prace Inst. Hutn.*, 1960, **12,** (1), 9–19) The article is concerned with the nitriding of Fe–Cr whose carbon content had previously been reduced to 0·03% *in vacuo*. The effects of temp., time, and grains size were investigated. The optimum conditions were found to be: nitriding *in vacuo* at 1100°C for 3 h using Fe–Cr of grain size 0·5 mm. Contents of N_2 of over 6% were obtained.

A continuous furnace for annealing tubes with slow cooling D. Drouffe (*Techn. Mod.*, 1960, **52** April, 203–207) This article describes a pass furnace heated with unpurified coke oven gas for the annealing of special steel tubes made by the Office Centrale de Chauffe Rationelle and Societé Lorraine Escaut. The process consists of treatment at constant temp. between 600° and 750°C and an annealing treatment with slow cooling. A detailed description of the furnace is given with special reference to the central equipment.

Possibilities of accelerating the soft annealing of steels with high carbon contents V. Dědek (*Hutn. Listy*, 1960, **15,** (1), 73–84) Possibilities of accelerating the annealing stage in the case of plain steels containing in excess of 0·7%C prior to hardening by quenching was studied. Cold work was found to accelerate the annealing. Details of the microstructures obtained under varying conditions of annealing are given and discussed.—P.F.

Extent of stress relief during the annealing of some weldable heat-resisting steels P. Brozzo (*Ing. Mecc.*, 1960, **9,** May, 29–39) An investigation is described which was carried out to establish the best conditions for stress-relieving of weldable heat-resisting steels. A torsion relaxation machine designed for this purpose is described and test conditions are specified. The results are given of tests on one Cr and three Cr–Mo-steels used in the construction of power installations. Finally, the shape of curves and their interpretation is discussed, expressing the amount of relaxation in relation to the temp.

Modern methods of annealing wire F. Frodsham (*Wire Wire Prod.*, 1960, **35,** Feb., 205–209, 248–249) A. Frederick Smith & Co., Wire Manufacturers Ltd, Staff school paper.

Dimensional changes of cold worked metals caused by low temperature annealing M. Okada and T. Watanabe (*Techn. Rep. Osaka Univ.*, 1959, **9,** March, 179–184) Dimensional changes due to annealing after cold-working of low carbon steels and of austenitic stainless steels were studied. In the case of low carbon steels the change occurs in the same direction as during the cold working but in the case of austenitic stainless steels it takes place in the reverse direction. This phenomenon was discussed in relation to the dislocation theory. Dislocations concentrated against the barrier by cold working have a tendency to migrate during low temp. anneals in such a direction that their stress concentration may be released. The direction of migration is affected by the direction of cold working, the strength of barrier and the affinity between a dislocation and its atmosphere.

Methods of annealing welded pipe joints subjected to high temperatures and pressures D. Calabro (*Ing. Mecc.*, 1960, **9,** March, 55–62) Steel required for the construction of large thermal power stations is difficult to weld because of its alloy content. The article recommends certain types of heat treatment to avoid structural alterations in the weld joints, which are described, together with the experimental results obtained.

Hot forming parts from 17-7 PH sheet A. F. Hofstatter (*Met. Prog.*, 1959, **76,** Nov., 88–90) Control of warping by a die quenching treatment is described with operating details.

Steels for pneumatic chisels N. K. Ipatov (*Stal'*, 1960, (5), 465–467) Grade 6052 is recommended and quenching and tempering conditions are laid down.

Determination of the quenching capacity of quenching oils. II. The value and suitability of various test procedures (**Das Industrieblatt*, 1959, July, 321–324) Various methods for determining quenching capacity are classified and examined for their suitability for standardization. It is shown that values in different temp. ranges and the use of two procedures are necessary. The austenitic cylinder and temp. rise procedures seem to be suitable for standardization (13 refs).

Improving rail quality by deep quenching S. V. Gubert and D. M. Rabinovich (*Stal'*, 1960, (5), 434–439) The development of an oil-quench process at Nizhne Tagil is described and the heat treatments tried and properties obtained are given. Designs for a new continuous production line are briefly considered.

Quenching effects on the properties of metals and alloys J. Takamura (*Met. Phys.*, 1959, **5,** July, 135–146) [In Japanese] (68 refs).

Heat treatment in sealed quench atmosphere

furnaces Ipsen Ind. Inc. (*Machine Shop Mag.*, 1960, **21,** Feb., 96–99) The furnace is described, with diagrams. It is used for carburizing, carbo-nitriding, normalizing, annealing, and brazing.

Austempering typewriter parts D. Flannery (*Met. Prog.*, 1959, **76,** Nov., 91–93) Use of a mechanized salt bath installation and its effects on increasing production and lowering costs in the heat treating of type bars are described.

The effect of the alloy elements on the tempering processes of steel A. S Zav'yalov and M. I. Senchenko (*Metallov. Term. Obra. Met.*, 1959, (12), 2–11) Alloying steel with non-carbide forming elements (Si, Al, etc.) impoverishes the zones containing these elements in carbon and increases the temp. of the martensite transformation during the tempering process. These elements condition the redistribution of the carbon towards the grain boundaries and increase the tendency of these steels to hot brittleness. In steel alloyed with carbide-forming elements the carbides of the cementite type may begin separating out at the same temp. as in carbon steels, but at these temp. only the carbon-containing martensite parts are involved in the process. The greater the proportion of carbon that will separate at the second stage of tempering, i.e. the greater the quantity of special carbides.

ROLLING MILL PRACTICE

Load calculation for a continuous sheet cold-rolling mill A. D. Machado (*Bol. ABM*, 1960, **16,** Jan., 5–19) Details of the method of calculation of the loading of the motors of the new, three-stand, continuous cold-rolling mill of CSN are given and the principles underlying the calculations are described. Rolling programmes, based on a scheme determined by the calculation of load distribution in the stands, allow a more rapid and easy synchronization between the electrical and mechanical parts when bringing the mill into use, avoid overloading, mean a shorter acceleration time to required rolling velocities, and increase component life. The method of calculation is applicable to all cold-rolling mills of three or more stands.—P.S.

Analysis of the forces and momentum in hot-rolling mild steel with reductions of thickness Z. Wusatowski and B. Hoderny (*Rev. Tech. Luxembourg*, 1960, **52,** April–June, 111–122) [In German] Tests enable the following conclusions to be drawn: The value of pressure decreases with increasing temp. and increases with thickness reduction with the ratio δ of the width to the height and of the height to the roll diameter at D—const. In the ratio $b_1 h_1 < 4$ for reductions in the range 50–80% and in the ratios $b_1 h_1 < 4$ for reductions in the range 50–70% the course of the curves is almost a straight line at individual temp., a sudden increase in pressure results in small ratios of b_1/h_1 in the range 80–90% reduction. The momentum value depends on the same factors as the value of the forces and its course is similar to that of the forces. Yet in recording the momentum of the upper roll and lower roll separately a difference of 30–40% was noted, the momentum of the upper roll continually increasing.

The manufacture of rolls for section rolling R. L. Pinheiro (*Bol. ABM*, 1960, **16,** Jan., 139–156) Details of roll production at CSN are given. The metallurgical requirements are discussed and the moulding and casting techniques are illustrated. Typical defects are listed together with their remedies. Grain iron rolls have not been found satisfactory for deep cut rolls. Finishing rolls, made of low-alloy cast iron containing 1·9 and 2·0%C have been found to have a satisfactory life. The depth of chill and uniformity of hardness are found to be of great importance in roll performance.

An analysis of the operation of roll bearings of continuous mills I. A. Al'men, V. V. Lepskii, S. M. Rubinskii (*Stal'*, 1960, (5), 441–445) Cylindrical roller bearings are recommended where no axial load is encountered, and radial thrust bearings for axial location of rolls where necessary.

Two new and modern rolling mills for Monlevade Belgo-Mineira Siderurgica Cia. (*Eng. Min. e Met.*, 1959, **30,** Dec., 358) A short account of the two-high reversing mill and continuous billet mill ordered for Monlevade is given. Some details of the increasing productivity at Belgo Mineiro are also supplied; about 350000 t of steel should be produced in 1959.

The effect of ingot shape on the condition of the bite I. D. Kuzema (*Stal'*, 1960, (5), 439–441) Choice of degree of taper is discussed. The angles calculated and those actually used at ten works are given.

Aspects of automation of Hungarian structural mills A. Kornlosy (*Koh. Lapok*, 1959, **14,** June, 255–262; July, 308–313) In the first part of the paper, the conditions of automation of a mill train are discussed. In the second part, the basic principles and main instruments of an automatic control are described; and in the third part, the draft for a plan of automation of two Hungarian structural mill trains is presented.—P.K.

Swedish type repeater mills for high quality steels E. Norlindh (*Iron Steel Eng.*, 1960, **37,** April, 77–110) An account is given of the way Swedish mills have overcome the difficulties of rolling large size ranges, with small tonnages for each size and low annual outputs, by means of extensive use of repeater rolling. Techniques and equipment are described in considerable detail.

The rolling of rods, bars, and light sections R. Stewartson (*Met. Rev.*, 1959, **4,** (16), 369–379) A review of the latest trends in mill layout and ancillary equipment for rolling rods, bars, and light sections. Pass design and factors affecting product quality are also discussed (34 refs).—A.K.

The effect of mill spring on gauge and the rolling of tapers C. W. Starling (*Sheet Metal Ind.*, 1960, **37,** April, 279–290) The author describes mill spring and describes methods of determining mill modulus. The roll gap transfer function is then introduced in relation to change of gauge and automatic gauge control. Taper sheets, which are required for certain applications in aircraft construction, can be rolled following the calculations of screwdown rates developed by the author. Examples are given.—A.H.M.

An efficient method of packaging sheets into bundles A. D. Kuz'min, K. S. Konveristyi, and I. B. Rubinstein (*Stal'*, 1960, (6), 542) A special press holding the sheets and welding strips around them is described.

Determining the initial diameter of wire in the production of narrow steel strip M. I. Zlotnikov (*Stal'*, 1960, (5), 476–479) Formulae are given for the spread of round wire rolled in smooth rolls with upset in the first pass. Strip suitable for mainsprings is produced.

New equipment and control techniques advance experimental rolling programmes at United States Steel Research Centre (*Indust. Heat.*, 1960, **27,** March, 537–538) Experimental equipment includes a two-high cold mill and ancillary plant, much of which is fully automatic. A technique of drilling and insertion of special thermocouples enables internal temp. to be read for up to 16 passes.—K.E.J.

Foundations for workshops and machines of a semi-continuous wide strip mill in a district of mining subsidences H. von der Warth and C. Scherer (*Stahl Eisen*, 1960, **80,** July 21, 990–1000) An extension of the existing mill of Hoesch Westfalenhütte was possible only over an area that showed mining subsidences. The work done for the special foundations is described and illustrated. The total additional costs for overcoming the mining subsidences were 6500000 DM.—T.G.

System analysis and design for hot strip mill with automatic gage control H. S. Maxwell and R. A. Phillips (*Iron Steel Eng.*, 1960, **37,** April, 111–118) The analogue computer study made prior to designing thickness regulators for the hot strip mill of Columbia–Geneva's Provo plant is described, and an account is given of the equipment and its operation.

The production of spring-sheet strip (*Sheet Metal Ind.*, 1960, **37,** March, 165–172) The article describes in some detail the Firth Cleveland's Tipton Works where high carbon steel strip is produced. The description includes works layout, the continuous pickle line, cold rolling, roll grinding, annealing, strip hardening and tempering, finishing operation, inspection, and testing.—A.H.M.

Control of thickness of metal sheet and strip J. Tobin and H. J. Hartley (*Sheet Metal Ind.*, 1960, **37,** March, 203–213) The authors start by describing the development in rolling mill design from the two-high mill to the complex Rohn–Sendzimir roll arrangement. Brief reference is made to gauge control in hot rolling and the case of cold rolling is then considered in greater detail. The main factors affecting gauge variation are discussed. Automatic gauge control is then described in general qualitative terms.—A.H.M.

The control of high-speed coil preparation lines of the tight-line type J. T. Bentley (*English Elect. J.*, 1960, March, 31–46) An account of the arrangements at the Velindre mill.

Strategic use of radiant burners in cold steel strip rolling controls gage within ±0·0002 of inch Alan Wood Steel Co. (*Indust. Heat.*, 1960, **27,** Feb., 317) Gauge is corrected and a degree of hardness is imparted after annealing by this installation on the top roll of the last cold-rolling stand. Nine gas-fired radiant burners are placed 3–4 in. from the face; any unevenness in gauge causes burners to ignite to swell the roll.—K.E.J.

Production of sections by cold-rolling 'Metron' (*Tecn. Indust.*, 1960, **38,** Feb., 203–205) Details of this technique are supplied using the Yoder Mill as an example. The type of material that may be shaped, the range of sections that may be produced, the cost factors and typical applications of the process are discussed.—P.S.

A new cluster cold mill for thin strip H. Niederstein and G. Heyer (*Stahl Eisen*, 1960, **80,** July 7, 926–930) A new small, 20-roll cluster mill for cold-rolling of high-strength strip and foil is described. The mill is a compact unit with drive and tension controls. The backing rolls are of a novel design that allows the camber to be altered. Converter steel 60 mm wide was rolled in four passes without intermediate annealing from 0·110 to 0·007 mm and 18·8 steel in three passes from 0·075 to 0·010 mm with a back tension of 50% of the proof stress. The electric control equipment is also described in detail.—T.G.

Grain size—its measurement and significance in relation to cold rolling V. L. James (*Sheet Metal Ind.*, 1960, **37,** March, 185–202) The author emphasizes the importance of grain size in the formability of sheet metals and describes methods of measuring grain size. Methods of selection and preparation of samples are described together with methods of revealing directionality. The article is concluded with an outline of the influence of grain size on mechanical properties.—A.H.M.

A survey of the steel pipe and tube industry of Canada T. H. Janes (*Canad. Dept. Mines Techn. Surveys, Min. Inf. Bull MR36*, 1959, Oct., pp.46) The companies producing pipes are reviewed.

Continuous tube rolling and expanding mills in Italy A. I. Tsclikov and V. P. Markov (*Stal'*, 1960, (6), 539–541) Details are given of the Costa Volpine Works, Bergamo and of the Dalmine Works, Milan.

The effect of the kinematics of a tube cold-rolling mill on the load conditions of the process Yu. F. Shevakin and F. S. Seidaliev (*Stal'*, 1960, (6), 537–538) A double rotation of the tube is shown to reduce load, improve quality, and increase output. The optimum radii for the leading roll pinions has been found.

Driving motors of blooming trains A. Szeghegyi (*Koh. Lapok*, 1959, **14,** Aug., 350–354; Sept., 397–401) The paper deals with the choice of type and capacity of reversible driving motors of blooming trains. In the first part the use of double motors is discussed. In the second part, two graphical methods are presented, one for rating the driving motor, another for determining the optimum rolling schedule in order to maintain the maximum efficiency of a given driving motor.—P.K.

Modern methods of control with mutators for heavy drives R. Zwicky (**Bull. Assoc. Suisse électr.*, 1956, **47,** (5), 155–159) A lecture. The topic considered is grid-control apparatus. The use of rectifiers (mutators) is briefly outlined

and then magnetic and electronic grid control methods are described. A drive for a continuous mill is shown in a diagram.

Rotary shears for longitudinal cutting I. G. Kulbatschny (**Mechanical Equipment for Rolling Mills*, 803–817, VEB Verlag Technik, Berlin, 1954; German translation of Russian original) The design of several types is described, and calculation of knife disc diameter, cutting speeds, and driving motor capacity are worked out.

Manipulator side-guard fingers operating synchronously with the fingers of an ingot turner N. D. Lomakin (*Stal'*, 1960, (6), 542).

WELDING AND FLAME-CUTTING

Effect of magnetic field on transfer characteristics of particles in an electric arc P. Shajenko (*Weld. J.*, 1960, **39,** Feb., 83s–88s) The conditions in which 'arc-blow', and thus inferior welds, occurred, were investigated. This led to a new hypothesis for explaining metal-transfer phenomena. This hypothesis explained observed phenomena, and was successfully applied in overcoming 'arc-blow'.

Properties of resistance cross-wire welds in stainless steel wire R. H. Espy (*Wire Wire Prod.*, 1960, **35,** Feb., 177–181, 244) Tests were carried out to show the effect of wire condition, grade, size, and welding conditions on the strength and appearance of resistance cross-wire welds in two types of stainless steel wire. Maximum weld tensile strengths were obtained when welding times of 30 cycles (at 60 cps) were employed to make welds having a mutual indentation of 30%. A graph specifies the welding pressure to be used. If appearance of the weld is important, the indentation should be reduced to 20% and a shorter welding time of four cycles employed; this results in only a moderate loss in tensile strength.

Effect of arsenic on weldability and notch toughness of mild steel (To A.P.I. grade B specification) (*Brit. Weld. J.*, 1960, **7,** Feb., 129–140) A literature survey was carried out by the British Welding Research Association, on the effect of As on the mechanical properties and weldability of steels, and experimental work was undertaken to assess the influence of As on the weldability and notch toughness of mild steel to the above specification. It was concluded that up to 0·1%As has no effect on these properties, and thus that British steels, which normally have an As content of half to one-third of this, are not inferior in this respect to steels of yet lower As content.

Synthetic heat-affected zone ductility test. A new test of weldability of high strength steel H. Suzuki and H. Tamura (*Trans. Nat. Res. Inst. Met.*, 1959, **1,** (2), 119–125) Round bar specimens with heat-affected zones produced by a weld thermal cycle are tensile tested. The method is described and results on eight high-strength steels are given. The values obtained are shown to be closely related to bead ductility and cracking susceptibility.

Build-up welding and metal spraying of axles subjected to fatigue K. Wellinger and P. Gimmel (*Werkstattstechn.*, 1960, **50,** May, 269–273) The authors report on tests in which axles after deposit welding and metal spraying were subjected to fatigue treatment. It was found that the fatigue strength of such parts is markedly lower than that in the original condition. The degree of reduction in fatigue strength depends to a large extent on the skill with which the welding or spraying has been done. Recommendations for proper welding and spraying procedures are included (23 refs).

CO_2-welding and some researches in this field carried out at the Czechoslovak Welding Research Institute L. Münchner, L. Lanyi, and A. Hrabovec (*Zváranie*, 1960, **9,** (1), 6–14) Details are given of research and development work on the application of CO_2-welding in industry, and a number of welding machines of recent Czechoslovak design are discussed. Some of the problems yet requiring attention are listed.—P.F.

Hydrogen in welding. Parallel between the behaviours of welded, cast wrought steels P. Bastien (*Soud. Techn. Connexes*, 1959, **13,** Sept.–Oct., 325–339) Ways in which H_2 is introduced into the metal and the essential characteristics of H_2 embrittlement are examined. It is shown that the initiation of defects of the sharp notch type is due to a combination of the effects of H_2 and mechanical stresses (36 refs).

Mechanical properties of joints welded by the electro-slag method O. Ižd'inský (*Zváranie*, 1960, **9,** (1), 15–18) Static and fatigue tests carried out on 0·4%C steel welds showed that the strength and fatigue resistance of the joints were virtually identical with the corresponding values of the base metal. This method of welding has excellent prospects for use in welded parts of highly stressed machines.

Physical processes in the slag pool in electro-slag welding Cheng En-kuei (*Zváranie*, 1960, **9,** (3), 80–83) The transfer of drops of molten metal from the electrode to the weld pool, and the circulation of the slag were studied. Drop size is influenced by the electrode composition and dimensions, by the source and polarity of the current, the surface tension of the molten metal and the welding conditions. The drop transfer is different from that occurring in submerged arc-welding; drops are generally larger n electro-slag welding. Drop formation and slag bath circulation are both influenced by the pinch effect.—P.F.

Are welds decarburized in resistance welding in which melting occurs? J. Malík and I. Hrivňák (*Zváranie*, 1960, **9,** (4), 103–107) It was shown electron micrographically that decarburization during welding of 0·12 and 0·30%C steels does not take place to any appreciable extent. What appear to be pearlite-free zones after welding are, in fact, ferrite with finely dispersed carbide. On annealing the weld can be made to revert to the usual ferrite–pearlite structure. The method of welding can influence the actual structure of this zone.

Effects of brittle fracture on welded structures (*Canad. Metalw.*, 1960, **23,** Feb., 16–18, 20) A report on a seminar of the Montreal Chapter of the Canadian Welding Soc. Abstracts of the papers are briefly given.

The contraction of welded joints I. Bizinger (*Per. Polytechn.*, 1959, **3,** (2), 123–145) [In German] It is shown that equations reported in the literature do not describe accurately the shrinkage found in practice, although the formula derived by Gilde (*Schweisstechn.*, 1957, **1,** 10–14) gives a good approximation. The results of shrinkage measurements on manual-arc and automatic welded specimens are plotted in a diagram from which the shrinkages of plates welded together can be read as a function of sheet thickness.

Influence of weld defects on the mechanical strength of welds M. Watanabe, K. Kamachi, O. Takagi, S. Nishi, S. Yamanonchi, S. Minehisa, and T. Terao (*Techn. Rep. Osaka Univ.*, 1959, **9,** March, 163–178) [In English] In studying the problems of establishing the relation between welding defects and the mechanical properties of welded joints it is difficult to obtain specimens of welds containing similar types of weld defects. This paper proposes artificial methods for obtaining weld defects in order to obtain data for the study. The types of artificial faults are blow holes, slag inclusions, poor penetration, cracks, undercut. The tests carried out are mechanical static, and impact tension tests, static and impact bending tests, and fatigue tests.

Some aspects of cracking in welded Cr–Ni austenitic steels J. C. Borland and R. N. Younger (*Brit. Weld. J.*, 1960, **7,** Jan., 22–59) This is an extensive review of the literature. The constitution of these steels is considered, followed by the nature and incidence of cracking, the factors affecting weld-metal and base-metal cracking, the theories of cracking in welds in steels of this type, and finally the authors draw some conclusions (162 refs).

The origin of a certain type of blowhole in relation to edge preparation in arc welding P. Berthet (*Soud. Techn. Connexes*, 1959, **13,** Sept.–Oct., 381–384) A special cause of blowhole formation is caused by the prevention of normal degassing of the weld pool by slag trapped between the plate edges. The importance of gap width is indicated.

Influence of stressing on the formation of fish-eyes in weld metal V. O. Valanti (*Soud. Techn. Connexes*, 1959, **13,** Sept.–Oct., 373–380) In the case of basic, acid, and rutile covered filler metal, there was no formation of fish-eyes in static tensile stresses on hydrogen-charged specimens below the yield point of the metal. The relationship between the appearance of fish eyes and changes in ultimate tensile and fatigue strength is explained on the basis of the amount of diffused H_2.

Metallurgy of bonding in brazed joints, Part III—The role of intermetallic compounds in brazed joints N. Bredzs and H. Schwarzbart (*Weld. J.*, 1960, **39,** Feb., 49s–58s) The work described was carried out on steel brazed with Ag–Si, Ag–Zn, Ag–Sn, and Cu–Fe–B alloys, in order to attempt to establish a 'critical concentration limit' for the formation of intermetallic compounds. The effect of intermetallic compounds on joint strength was also studied.

Helically welded steel pipe (*Weld. Met. Fabr.*, 1960, **28,** March, 116–117) The Driam machine recently installed at the works of the British Steel Piling Co. Ltd., for the continuous manufacture of helically welded steel pipes is illustrated and described.—S.H.–S.

How to weld galvanized steel J. F. Rudy (*Iron Age*, 1960, **185,** March 31, 154–156) The results of an investigation into the causes and prevention of weld bead cracking during the joining of thick galvanized steel plates are reported. Liquid Zn collects at the notched fillet throat and penetrates the steel grain boundaries, and weld cooling develops critical shrinkage stresses. The two most effective ways of reducing the cracking were found to be: the use of low penetrating electrodes; separation of the two surfaces by a $\frac{1}{16}$ in. spacer. The improvement by the latter technique is due to the opening of or reduction of the severity of, the notch at the fillet root.

Some uses of welding in fixed equipment of railroads and tramways Vandenberghen (*Soudage*, 1959, **13,** Feb., 31–33) The Sécheron (Geneva) method of electrically welding rails and rail joints is briefly described.—S.H.–S.

Welding operation on Diesel engine crankcase 'Skeletons' W. G. O'Leary (*Machinery*, 1960, **96,** April, 760–763) Steel crankcase skeletons for 6–8–12 and 16 cylinder V-type diesel locomotive engines are being fabricated by welding in the Chicago works of G.M.C., USA. The crankshaft incorporates two box-section girders set at an angle and each girder is weld fabricated. The girders are joined together by a long weld at the bottom of the Vee and by a tie plate at the top. The standard and special welding equipment used is described.

Electric arc welding of structures for Diesel engines V. Losana (*Riv. Ital. Saldatura*, 1960, **12,** (1), 3–11) After examining the advantages in certain cases of welded crankcases for diesel engines compared with castings, the article describes techniques of manual, semi-automatic, and mixed welding used to make various types of joints and the tests which are used, with particular reference to ultrasonic tests.

The electro-slag welding of a hydraulic turbine shaft with a welded shell A. S. Gel'man, S. N. Mel'bard, S. E. Sinadskii, and P. I. Cheshev (**Svarochnoe Proizv.*, 1958, (9), 26–32) The results of a joint study to find suitable materials and a rational technique for manufacturing the welded shafts of hydraulic turbines are reported.

Repair of a kiln by welding A. Happernegg (*Schweisstechnik*, 1959, **13,** Dec., 133–135) A welded kiln that is used for the sintering of magnesite showed cracks near the tread. The torch welding of these cracks, including preparation of the seams, is described. The kiln has been used since welding for several thousands of h and no new cracks have appeared.—T.G.

Automatic welding procedures for sheet-metal stampings H. A. Franke and E. R. Hubbard (*Weld. J.*, 1960, **39,** Feb., 126–130) The advantages of automatic handling are enumerated, and various procedures and types of equipment are considered.

Welding in the construction of nuclear plant E. B. La Velle (*Riv. Ital. Saldatura*, 1960, **12,** (1), 12–20) The need for the absolute reliability of nuclear installations poses special problems in construction and maintenance, related to the quality of the weld, security of

personnel, possibility of repairing contaminated installations, and tubing. The importance of proper supervision of welding, the choice of methods and processes, the use of qualified welders, and appropriate tests are discussed.

Ring-projection welding of low-carbon steel munitions M. J. Welther and S. M. Robelotto (*Weld. J.*, 1960, **39,** Feb., 118–125) Ring-projection welding was investigated due to low output, high machining costs, and rejection rate of munitions closures, and because very little heat is used in this method, as compared with brazing or fusion welding. It was found that by careful joint design, electrode design, and weld-scheduling, it was possible to obtain good physical strength welds, with a very low helium leakage rate, in production simulation runs of 100.

Electroslag welding—a new process for heavy fabrication R. D. Thomas jun. (*Weld. J.*, 1960, **39,** Feb., 111–117) In 'electro-slag' welding, the heat required for the operation is generated in the slag. This type of welding gives substantial savings in the welding of steel plates 2 in. thick and over. All work is done in the vertical position. The process is completely continuous, and the deposition rate is 35–45 lb of weld metal/h/electrode. Savings in flux and filler metal quantities more than offset the rather more expensive fluxes used.

Ultrasonic welding of dissimilar metal combinations W. C. Potthoff, J. G. Thomas, and F. R. Meyer (*Weld. J.*, 1960, **39,** Feb., 131–138) The advantages of ultrasonic welding for thin sheets are described, and examples of the very good properties obtained by this method are given. The avoidance of fusion, and thus of intermetallic compounds, is of particular importance in the case of dissimilar metal welds, and this advantage is stressed.

Dynamic behaviour of D.C. generators for arc welding A. Carrer (*Brit. Weld. J.*, 1960, **7,** Jan., 6–14) Oscillographic work on the 'suitability for welding' of a series of welding generators are described, and this 'suitability for welding' is defined in terms of a coefficient r (the ratio of the minimum value of the power of the arc to the average power under steady conditions), or a less precise coefficient e. When r > 0·6, or e > 0·7, the generator is considered to be suitable.

Careful electrode choice vital to good welding R. R. Irving (*Iron Age*, 1960, **185,** April 21, 145–148) The 'AWS–ASTM' electrode specification system is explained and the field of application of each type of electrode is described.—D.L.C.P.

Development of high-strength filler wires for welding SAE 4130, 4140, and 5340 steels H. W. Mishler and R. P. Sopher (*WADC Techn. Rep.* 56–550; *ASTIA Doc. No. AD* 118210; *PB* 131074, 1957, April, pp.69) The filler wires developed were for welding high-strength low-alloy aircraft steels by the inert-gas consumable electrode processes.

Electrodes with non-oxidising coatings A. A. Erokhin and O. M. Kuznetsov (*Svarochnoe Proizv.*, 1959, (12), 1–4) A suitable coating from the technological point of view is CaF_2 70–85 parts by weight, marble 10–20 and TiO_2 5–10. The composition of some other coatings is given.

Considerations on the use of wires and fluxes in submerged arc welding A. Cergna (*Riv. Ital. Saldatura*, 1960, **12,** (2), 66–70) The economic aspects of consumption rates in submerged arc welding of steel plates are considered. On the basis of experiments carried out with four different types of fluxes and the same wire both in DC and AC it is pointed out that a lower flux consumption may lead to a greater wire consumption so that under equal conditions the szme flux is uneconomical. The physical properties of the fluxes are compared.

Attachment for regulating the supply of wire electrode in electrical welding G. G. Demidov (*Svarochnoe Proizv.*, 1959, (12), 21–23) An attachment is described automatically regulating the supply of wire electrode in relation to its consumption as it passes through it. The mechanism is mounted on a plate rotating round its horizontal axis without disturbing the connection so that the electrode may be fixed at any required angle.

Autoradiographic study of resistance welds B. Žitňanský (*Zváranie*, 1960, **9,** (2), 34–39) In resistance welding low carbon steels without melting in the weld zone the carbon is uniformly distributed in the latter, pearlite islands being absent. After normalization the usual ferrite–pearlite structure reforms.—P.F.

On the design of fillet welds subject to shear and tension F. Faltus (*Zváranie*. 1960, **9,** (1), 2–5) The design of sections and welds subject to complex static and fatigue loading is discussed in the light of the author's experiments.

The effect of oxygen additions to the CO_2-shielded metal arc A. A. Smith (*Brit. Weld. J.*, 1960, **7,** Jan., 15–19) The effect of adding excess oxygen to the CO_2 shielding gas in the inert-gas metal arc has been investigated. The burn-off rate and droplet transfer frequency of the process are not affected by the addition of up to 10%O_2. In larger amounts, up to 100%O_2, the droplet transfer rate is still unaffected but gross porosity occurs, depending on the de-oxidizing qualities of the filler wire.

Diffusion bonding: new way to join critical parts W. P. McQuillan (*Mat. Design. Eng.*, 1960, **51,** April, 14–16) Producing a joint with a controlled microstructure similar to that of the base metal is essential to obtain optimum strength and corrosion resistance. In many assemblies such as the atomic reactor bundle described in this article it is difficult to preplace a brazing alloy—welding is often unpractical. The answer may be in suitable ways of diffusion bonding.

A process of brazing and welding by gas torch J. Delforge (*Soudage*, 1959, **13,** Feb., 25–29) Simple examples of brazing and welding are illustrated and described.—S.H.–S.

A new brazing technique (insitu brazing) (*Prec. Met. Mold.*, 1960, **18,** April, 59) This note describes how by mechanically mixing a selected metal powder with brazing alloy powder it is possible to produce brazed joints with special characteristics. Among the advantages are serviceability of joints at high temp., higher impact and fatigue properties, tougher joints, better control of size of both fillets and bronze puddles, less erosion of the base metal, possibility of multiple brazing cyles.

The scope of mechanized flame brazing in production V. Ruža (*Zváranie*, 1960, **9,** (2), 50–54) A number of cases in which industrial capillary brazing is advantageous and productive are discussed, e.g. in the production of tubular furniture, skates, junction pieces for water ducts, etc. A wider introduction of the method into Czechoslovak industry is urged.

Brazing stainless steel honeycomb T. A. Dickinson (*Machine Shop Mag.*, 1959, **20,** Dec., 681–686) Methods used by North American Aviation Inc., are described and illustrated.

Automatic machine reduces brazing time by 60% (*Steel*, 1960, **146,** March 21, 162) An automatic machine for brazing Stellite strips to steam turbine blades is described. Machine time is 2 min. and heating is effected by high velocity burners.—D.L.C.P.

Automatic brazing of air-intake grille for jet engines (*Weld. J.*, 1960, **39,** Feb., 140) The way in which a French manufacturer avoids distortion during brazing of a grille by adopting a particular welding procedure is described.

Fused silicon glass insulates portable brazing furnace (*Iron Age*, 1960, **185,** April 7, 102–103) The use of 'Foamsil' blocks for insulating a large brazing furnace is described. The blocks are a lightweight easily-cut pure fused silica foamed glass material, which has a very low specific heat. The furnace treats honeycomb sections, up to 12 × 20 × 4 ft in size. Features are: the furnace is portable allowing the sections to be held before brazing; quick heating and cooling; economy in fuel and firing equipment.—D.L.C.P.

Natural-gas cutting equipment aids fabrication of pipes L. H. Paine (*Weld. J.*, 1960, **39,** Feb., 139) The use of natural-gas cutting for cutting to size and bevelling of mild-steel plates prior to rolling, and for separating up and bevelling after forming of the pipes, is described and illustrated.

Oxyacetylene cutting and arc-welding in metallic construction (*Prat. Soud.*, 1958, **12,** Dec., 201–203) The assembly of a bridge in the workshop by the combination of oxyacetylene cutting of steel plate, and the electric welding of resultant members is described.—S.H.–S.

Powder cutting in the fettling of castings B. Brandstedt (*Gjuteriet*, 1960, **50,** (4), 51–57) The use of powder cutting for cleaning up castings and scrap cutting. Improved modern techniques are described and illustrated by examples (18 refs).

MACHINING AND MACHINABILITY

Drive problems in machine tools H. Petrick (*Draht*, 1959, **10,** Aug., 375–378) Various types of drive and their controls are reviewed briefly.

Transfer line tackles variety in machining pump housings (*Iron Age*, 1960, **185,** Feb. 4, 96–97) A 76-station palletized transfer machine suitable for making pump housings is described.—D.L.C.P.

New production equipment G. W. Mason and A. J. Barker (*Machinery*, 1960, **96,** April, 771–776) A description is given of a new range of counter blow hammers introduced recently by B. & S. Massey Ltd, a hacksawing machine built by the New Fortuna Machine Co. Ltd, a rotary table built by Fritz Wendt AG, Dusseldorf, for surface grinding WC and ceramic tips for cutting tools, a hydraulic press by William Jones Ltd, a universal milling machine with pivot-mounted vertical attachment made by Misal SAS of Milan, an air-operated indexing table made by Thirelecke & Co., of Karlsruhe, and a BHP Group A Feed air-operated unit.

The production of the SIMCA Aronde P. A. Sidders (*Machinery*, 1960, **96,** April, 748–759) A description is given of methods and equipment employed for the manufacture of rear axle casings for the Aronde car up to the main machinery sequence. An illustration is given of the layout of operations performed on a six-spindle New Britain chucking automatic for machining bearing housings, also a table giving data on the sequence of operations and a diagram showing the layout of part of the SIMCA machine shop where the rear axle casings are assembled, welded, and machined.

Dimensional tolerances and machining allowances for mass-produced unalloyed pig iron castings Fiocre (*Mét. Const. Méc.*, 1960, **92,** May, 355–361) A document under the joint segis of the Féderation des Industries Mécaniques and the Syndicat Général des Fondeurs de France, dealing with methods of application, and comparison with foreign systems is published.—S.H.–S.

Metal cutting machine tools M. Seybold (*VDIZ*, 1960, **102,** June 1, 663–667) A review of developments in 1959, with reference to the literature (102 refs).

The cold hobbing of forging dies K. Schimz (**Industrie-Anzeiger*, 1957, **79,** Oct. 8, 1217–1220) Factors influencing the efficiency of the operation are discussed; these include composition, rate of deformation, and correct specific hobbing pressure. Several examples are given, and economic aspects are reviewed.

Cutting pressure and energy with parallel knives I. G. Kulbatschny (*Translated from *Mechanical Equipment for Rolling Mills*, 782–788. VEB Verlag Technik, Berlin, 1954—a German translation of a Russian original). A mathematical analysis of the cutting pressure for shears with parallel knives.

Metallurgy of metal cutting E. M. Trent (*J. B'ham. Met. Soc.*, 1960, **40,** March, 3–22) A review.

Flow stress in metal cutting T. Sata (*Sci. Papers Inst. Phys. Chem. Res.*, 1959, **53,** Sept., 188–200) [In English] Flow stress is examined by considering strain, strain rate, and temperature in the flow region.

Machining metal at ultra-high speed Lockheed Aircraft Corp. (*Engineering*, 1960, **189,** May 6, 622–623) Experimental studies on AISI 4340 steel and other materials at rates of which an optimum was found at 120000 ft/min for the conditions used are described. Measurements of forces and temp. are noted and also observations on tool wear. Possibilities of applying the results are briefly considered.

New machine smooths contoured parts J. F. Harper (*Products Fin.*, 1959, **24,** Oct., 24–28) This article describes a machine recently developed by Harper Buffing Machine Co. which improves the finish of metal parts by processing in loose abrasives in a manner quite different from conventional barrel finishing. It

reduces finishing time and processes intricately contoured parts.

Ceramic cutting materials H. Staudinger (*Werkstattstechn.*, 1960, **50,** May, 254–262) A review on the history of ceramic cutting materials, their properties, use as tool tips and the clamping of the tips, the cutting power of the materials, and their limitation in application. A list of manufacturers of ceramic cutting materials is included (16 refs).—T.G.

How Alvis use ceramic tools R. M. Gill and G. Spence (*Metalw. Prodn.*, 1960, **104,** March 30, 561–565) Three case studies are given.

Machining Ford Anglia front hubs with throwaway tip tools R. E. Green (*Machinery*, 1960, **96,** May 4, 988–993).

Flank wear on a sintered oxide tool bit A. Gibson (*Machinery*, 1960, **96,** April 27, 933–936) A film of metal may become attached to the flank and is difficult to detect. It must be etched away to give correct values for flank wear.

New machinable carbides stand up to 1650 F Chromalloy Corp. (*Steel*, 1960, **146,** March 14, 99) .**Build your own carbide tools** (*Iron Age*, 1960, **185,** April 7, 104) The use of a steel bonded titanium carbide material for making tools is described. The material is made by powder metallurgy by which tiny crystals of TiC are embedded in stainless or low-alloy steel. This can then be machined by conventional tools to the required shape and is suitable for high temperature forming. The material is also valuable for other applications requiring hard, corrosion resistant metal.

Standard shop tools machine difficult exotic alloys J. E. Laibach (*Iron Age*, 1960, **185,** March 31, 162–163) Conditions which must be observed in order to be able to drill, mill, and turn Ti and other special metals with standard shop machining equipment are explained. This can be done if operations are carefully planned; water-base coolants should be used, and high speeds and low feed rates are essential.

Cutting oils and coolants J. J. Obrzut (*Iron Age*, 1960, **185,** March 3. **What does a cutting fluid do?** (87–89). **Match cutting fluid to the job** (90–92). **How metals influence selections** (93–95). **Tooling: Speeds and pressures exert heavy burdens** (96–99). **Care of cutting fluid pays off** (100–102).

Short cut to machinability determination A. Ashburn (*Metalw. Prodn.*, 1960, **104,** March 30, 568–570) A mathematical approach which may solve problems of machinability by means of a few tests.

The dynamic performance of a milling machine F. Koenigsberger and S. M. Said (*Prodn. Eng.*, 1960, **39,** May, 270–290) An exhaustive study of vibrations in the machine is reported. A procedure simulating working conditions was used and the findings are correlated with surface finish.

Milling stainless steels Boeing Airplane Co. (*Machine Shop Mag.*, 1959, **20,** Nov., 651) A combined routing and climb cutting process working with CO_2 cooling is briefly described.

Liquid honing F. Neuberger, L. Moeckel, and L. Roetz (**Fertigungstechnik*, 1957, **7,** (9), 413–417) Procedures, types of equipment, process variables, and testing procedure are reviewed.

Technological machinings by electro-erosion G. B. Gamondi (*Ing. Mecc.*, 1960, **9,** April, 25–33) A detailed description is given of a sharpening-shaping machine made by Elox–Cincinnati for tool sharpening and a comparison is made between electro-erosion sharpening and conventional grinding wheel sharpening processes.

Precision grinding research H. Grisbrook (*Prodn. Eng.*, 1960, **39,** May, 251–269) Factors important in grinding are considered and the construction of a dynamometer attached to a commercial grinding machine is explained. Results are then given and discussed.

The structure of the secondary hardened layer appearing in grinding V. A. Landa (*Metalloved. e Term. Obra Met.*, 1959, (12), 12–18) The temp. developing during grinding can exceed 1000°. This was established by studying the structure transformation. The structure of this secondary hardened layer consists of a mixture of austenite and martensite (90% austenite) with a hardness exceeding the martensite hardness. The distortion of the IInd order measures $2{\cdot}10^{-3}$ mm and the mosaic blocks about 500 Å.

Tape control for boring mill adds fast setup and versatility R. H. Eshelman (*Iron Age*, 1960, **185,** March 17, 99–101) A non-technical account.

Spark machining joins band cutting team DoAll Co. (*Steel*, 1960, **146,** March 28, 90) Machines for applying the technique of 'quenched arc cutting' to fragile honeycomb structures are described. An electric arc cuts the material by erosion as the part is fed to a rapidly moving blade. A low-voltage high-current power supply sustains the arc at the leading edge. A flood of coolant limits the arc and localizes the heat. Advantages of the method are: little waste, no burrs, little distortion.—D.L.C.P.

Koib travelling-head machine for drilling large steel plates (*Machinery*, 1960, **96,** Feb. 3, 246–248) The design and operation of a travelling head machine for drilling on a fully or a semi-automatic cycle, numerous holes at equal centre distances in large steel plates for boilers, heat exchangers, etc. The machine is built by Hermann Kolb of Germany.

How to minimize and control residual machining stresses R. D. Halverstadt (*Metalw. Prodn.*, 1960, **104,** March 30, 571–577) The causes, detection and measurement, and control of residual stresses are discussed with some practical problems and solutions.

CLEANING AND PICKLING

Shot cleaning of convection heat-exchange surfaces D. Humphrey (*J. Inst. Fuel*, 1960, **33,** April, 163–175) Shot cleaning which is comparatively new to this country is now being specified on many heat exchanger plants. This paper describes this method with special reference to the equipment used and its requirements for installation. Conventional methods are briefly reviewed for purpose of comparison.

Technical developments of 1959 N. Hall (*Met. Fin.*, 1960, **58,** Jan., 42–53) A comprehensive review and bibliography of cleaning, polishing, plating, and casting (470 refs).

Alkaline cleaning of metals. Part I. Cleaner formulations and cycles ASM Metals Handbook Committee (*Met. Prog.*, 1959, **76,** Nov., 108–116) A review; to appear later in the handbook. **Part II. Selecting equipment, maintenance and costs** (Dec., 103–113, 162, 164).

Scale removal as pretreatment for the application of primers and protective coatings H. Anders (*Metall–Rein. Vorbeh.*, 1960, **9,** May, 72–75) The various cleaning processes in use for the removal of scale and oxides from steel surfaces are reviewed including flame scarfing and past application. The only guarantee of good adhesion of a protective coating is the complete removal of the scale. Cleaned metal parts show excellent corrosion resistance after being painted with 'Protector' and 'Super-protector', two proprietary protective paints.

Improvement of the technology for pickling and heat-treating stainless steel G. F. Chub (*Stal'*, 1960, (5), 457) A note from Zaporozhstal'. No details are given.

New knowledge of pickling with phosphoric acid and the treatment of waste water R. Moran (*Metall–Rein. Vorbeh.*, 1960, **9,** May, 69–71) The advantages of using H_3PO_4 for the pickling of steel are stressed. Regeneration of the pickling bath is carried out with the aid of ion exchangers. As alkalies are used in the rinsing process after pickling, the waste water is usually neutral, or can at least be easily adjusted to the required pH value.—T.G.

How to work with stainless to get sanitary finishes R. H. Waters and W. A. Corse (*Iron Age*, 1960, **185,** Feb. 25, 76–78) Hints are given on grinding and polishing stainless steel tanks for dairy and food use.—D.L.C.P.

The nature of mechanically polished surfaces L. E. Samuels (*Proc. Amer. Electropl. Soc.*, 1959, 122–127) Recent experimental work indicates that the primary mechanism of polishing is cutting and not smearing. The polished surface is crystalline and plastically deformed (39 refs).—A.D.H.

Electropolishing in the United Kingdom. Its prospects and limitations H. E. Z. Gordon (*Proc. Amer. Electrop. Soc.*, 1959, 390–392, discussion, 384) The development of electroplating and its actual and potential applications are discussed.—A.D.H.

Nail automation challenges foreign competition R. H. Eshelman (*Iron Age*, 1960, **185,** March 31, 149–151) Recently developed techniques for handling nails after production are described. Modern cleaning and packaging lines make use of the magnetic conveyor which will transfer nails almost vertically, magnetic packaging, and compact vibratory degreasing.

Progressive die with automatic transfer equipment for furniture nails W. Leinhart (*Machinery*, 1960, **96,** Feb. 3, 237–239) A description is given of an early mechanical finger arrangement for advancing individual steel workpieces automatically through progressive dies for making furniture and upholstery nails developed by the Millwood Mfg. Co., Cleveland, Ohio, USA.

How coated metals affect forming, shaping steps (*Iron Age*, 1959, **184,** Oct. 22, 208–210) Recommendations are made for the degreasing, forming, and shaping of both plastic-coated and pre-enamelled steel sheet.—A.G.

PROTECTIVE COATINGS

Metal finishing in Europe today D. A. Marino (*Met. Fin.*, 1960, **58,** (2), Feb., 50–54, 62) West German equipment and practice for plating and enamelling are described.—A.D.H.

Why switch to coated metals (*Iron Age*, 1959, **184,** Oct. 22, 200–201) The various coatings available are briefly listed together with the advantages arising from their use.—A.G.

Low cost coatings for metal products R. J. Fabian (*Met. Des. Eng.*, 1960, **51,** March, 123–138) A survey of coating systems including selected organic coatings, chemical conversion coatings, and rust preventives.—S.H.–S.

Problems encountered in the application of prefinished metal S. Wernick (*Proc. Amer. Electrop. Soc.*, 1959, **43–49**; discussion 359–360) The production, characteristics, and fabrication of electroplated, painted and plastic coated steel sheet are described.—A.D.H.

Experimental studies of the electrodeposition of metal in narrow crevices L. B. Garmon and H. Leidheiser jun. (*Proc. Amer. Electrop. Soc.*, 1959, 50–60; discussion 360–362) The effect of bath variables on the distribution of electrodeposits from nickel, cobalt, and copper baths with a crevice 0·07–2·1 mm in width and 8 mm deep was determined. In general, the amount of deposit in the crevice increased with increase in metal ion concentration and in the conductivity of the bath. For nickel, the ability of the baths to form a large amount of deposit decreased in the order: all-chloride, Watts, all-sulphamate, and all-sulphate.—A.D.H.

Protection of metallic surfaces against tropical climatic conditions by various coatings V. Negrescu (*Met. si Constr. Masini*, 1959, (11), 386–392).

Finishing is part of production at Saginaw Steering Gear E. A. Blount (*Products. Fin.*, 1959, **24,** Oct., 30–35) Saginaw Steering Gear Division of General Motors Corporation make manual and power steering gear units and various mechanical assemblies used in road vehicles and heavy off-the-road equipment. This article describes the finishing operations in the plant which include ultrasonic degreasing, Cu plating, and painting.

Finishing facilities in new Westinghouse plant (*Products. Fin.*, 1959, **24,** Oct., 62–64) Westinghouse Electric Corporation new plant in Bloomington, Indiana, is intended for the design, manufacture, and marketing of capacitors and protective equipment used in the distribution of electric power. The new plants finishing operations include electroplating, galvanizing, hot-tip-tinning, and bright-dipping. The operation of the Stevens automatic bright dip machine is described in detail.

Process makes plating comparable to painting Steel Improvement & Forge Co. (*Steel*, 1960, **146,** March 28, 98) Electroplating by the 'Dalic' process is described. After preparation the surface is rubbed with a saturated anode pad and the deposit thickness controlled by an ampere-hour meter. Many metals can be deposited. The technique is ideal for plating on

selected areas, or parts 'in situ' or which cannot be immersed in a bath.—D.L.C.P.

Measurement of coating thickness using statistical methods F. Goubeaud (*Draht*, 1959, **10**, Aug., 370–374).

Testing and examination of electrodeposits: 4 Measurement of haze R. Quarendon (*Products. Fin.*, 1960, **13**, April, 98–102) Surface finish examination, mainly by means of the interference microscope, is described.

Electrodeposits as resists in selective heat treating R. S. Modjeska and S. P. Gary (*Prod. Amer. Elec ropol. Soc.*, 1959, 333–337, discussion 388–389) The efficiency of Cu, Sn, Ni, Ag, Cr, and bronze electrodeposits in preventing carburizing and nitriding were investigated. With the exception of Cr those metals which formed no carbides and which were of adequate thickness resisted penetration. No nitrogen was absorbed by those metals which do not form nitrides.—A.D.H.

A black chromium plating process A. K. Graham (*Proc. Amer. Electrop. Soc.*, 1959, 61–63; discussion 362) Black Cr deposits of high abrasion resistance applied over a Ni undercoat are produced at relatively low current densities in baths containing chromic acid and fluorsilicic acid. The characteristics of other less satisfactory baths are described.—A.D.H.

The electrodeposition of iron chromium alloys from complex chromium (III) sulphate solutions W. Machu and M. F. M. El-Ghandour (*Werks. Korr.*, 1960, **11**, May, 274–283) The conditions have been studied under which Fe–Cr alloy deposits may be obtained from Cr (III) sulphate, iron (II) sulphate, and urea and ammonium sulphate. The two metals mutually hinder deposition, this is evident from the cathode current efficiency, particularly that of iron. Brightness of the alloy deposit is always lower than of the individual metal alone. The alloy shows—under the most favourable conditions of deposition, a Cr content of 18–20%, the cathode current efficiency is below 30% and that of the Cr is always below 10%. The deposits show cracks, these can be avoided by raising the temp., lowering the current density, and adding boric acid.

Gauges for measuring the thickness of chromium on the internal surface of small-bore tubes V. A. Lamb and P. A. Krasley (*Plating*, 1960, **47**, Feb., 176–179) Gauges of eddy-current type for use with 0·30 and 0·50 calibre barrels, for which standard Magne and Woolwich electrical inductance gauges designed for larger bore diameters were unsuitable, are described as being successfully applied to American military weapons, both small calibre and cannon. Performance is discussed and evaluated.—S.H.–S.

Science for electroplaters: 54. The Rochelle salt bath L. Serota (*Met. Fin.*, 1960, **58**, Jan., 73–75; (2), Feb., 75–76, 79) The operation of Rochelle salt nickel plating baths and their characteristics are reviewed.—A.D.H.

The effect of urea on the electrodeposition of nickel W. Machu and M. F. M. El-Ghandour (*Werks. Korr.*, 1960, **11**, May, 283–286) Additions of urea to the nickel sulphate bath impair the deposition of the Ni but they bring about a marked brightening effect. Although the cathode current efficiency is reduced to less than 50%, the use of urea may have practical advantages as very high current densities of 20 amp./dm² may be applied. The Ni contents of baths can be as low as 140 g/l. (as the sulphate), but in spite of the high current density the deposits are always bright.—T.G.

Electrodeposition of nickel alloys from the pyrophosphate bath T. L. Rama Char (*Proc. Amer. Electrop. Soc.*, 1959, 76–80; discussion 363–364) Bath compositions and conditions are given for the co-deposition of nickel with Sn, Cu, Co, Zn, and Fe respectively from pyrophosphate baths. Preliminary results indicate that the process can be used for the deposition of alloys of Ni with Mn, W, and Mo. (29 refs)

The influence of the physical metallurgy and mechanical processing of the basis metal on electroplating. VI. Ferrous metal conditions affecting the durability of Watts nickel deposits M. H. Jones, Chih-yen Lu, A. F. Mohrnheim, and J. Zajdowski (*Proc. Amer. Electropl. Soc.*, 1959, 113–121; discussion 367) The influence of non-metallic inclusions, polishing, and deformation caused by drawing or polishing on the corrosion resistance of Watts nickel deposits of thickness up to 0·001 in. was determined. Although the nature of the corrosive environment may affect the relative importance of the effects, better corrosion resistance is obtained with smooth surfaces, and with highly deformed surfaces. Sulphide inclusions are a less potential source of failure than alumina or silica.—A.D.H.

Use of disodium *m*-benzenedisulphonate as a hardening agent in a Watts nickel bath W. H. Metzger, jun., P. A. Krasley, and F. Ogburn (*Plating*, 1960, **47**, March, 285–287) The agent, used in response to a request from the Bureau of Engraving and Printing, increases deposit hardness to a maximum of 350 VHN. Data kept during a period of six months are discussed and the claim is made that the use of the hardener has been very successful during production experience.—S.H.–S.

Electroless process for chemical nickel plating W. J. Crehan (*Corrosion*, 1960, **16**, April, 23–24) The author describes the Kanigen electroless process of chemical nickel plating. The properties of the coating are given and its application in corrosion control is discussed.

Age hardening of chemical nickel coatings W. G. Lee (*Plating*, 1960, **47**, March, 288–290) Tests on the Kanigen process are described and a table of the effect of annealing time on VHN at various isotherms from 190·5°C to 315·6°C is given, the claim being made that annealing should be for a period sufficient to take the coating hardness past the maximum and then down again will give maximum ductility at the lower VHN values.—S.H.–S.

The adhesion of fused silicate to low alloy steel A. A. Perminov, S. I. Popel', N. S. Smirnov, and V. P. Zhukova (*Izvest. VUZ Chern. Met.*, 1959, (10), 3–7) It has been experimentally demonstrated that the work of adhesion of liquid silicate (59%SiO_2, 3%Al_2O_3, 23%Na_2O, 14%CaF_2) to the surface of iron at 860° is 250 erg/cm² and remains practically constant with small addition (of up to ~0·4%) of Ti, Ni, Co, Cr, and Cu. The oxidation in air at that temp. for 30–60 sec. increases the adhesion to 500–600 erg/cm². Continued oxidation has no effect. Addition of small quantities of the above metals reduces the rate of oxidation and causes a reduced adhesion of the enamel.

Good practices in painting steel elevated tanks and standpipes J. O. Jackson (*J. Amer. Water Works Assoc.*, 1960, **52**, Feb., 191–198) Surface preparation, painting practices, and the use of vinyl-base paints are discussed with a note on Pb toxicity.

Paint as protection of metal surfaces (*Mét. Const. Méc.*, 1960, **92**, May, 381–385) The roles of three main factors, pigment, vehicle, and solvent, are described with the conclusion that the efficacy of paint as a protection of metal surfaces against corrosion depends upon their proper balancing.—S.H. S.

Multicolour coatings for corrosion protection N. I. Gaynes (*Met. Fin.*, 1959, **57**, Sept., 73–75) Salt spray and outdoor exposure tests were used to assess the suitability of various priming paints as a basis for multicolour paints on phosphated mild steel. Alkyd and PVA primers were better than zinc chromate base paints.

Paints for underwater use (anti-fouling paints) K. A. van Oeteren (*Werks. Korros.*, 1960, **11**, April, 209–212) Nature of corrosive attack, requirements to be met by these paints, and assessment of the various coatings are dealt with.

The metal surface conversion coating as a paint base R. C. Gibson (*Proc. Amer. Electropl. Soc.*, 1959, 93–95; discussion 365) Chemical cleaning and the chemistry of phosphate coatings as a basis for paints are described.

CLAD SHEET AND HARD FACING

Development of clad metals (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 26) A process for cladding Al on mild steel is described. Mechanical tests were satisfactory and metallographic examination of the bond zone revealed thorough diffusion of metals across the interface. Attempts are now being made to evolve a method for continuous production of clad sheets using Al foil of suitable thickness.

Veriform type 100 hard chromium plating unit (*Machinery*, 1960, **96**, Feb. 3, 252) With equipment produced by Coventry Gauge & Tool Co. Ltd, surface areas up to 50 in² can be hard Cr plated. Larger capacity units can be provided. The process is intended for plating small precision components to give high resistance to wear and corrosion. An important advantage claimed is that thickness of coating is accurate to 0·0001 in. so that need for subsequent grinding and lapping is avoided. Ordinary and alloy steels can be plated.

Paste hard coats conveyor: alloys with base metal to form abrasion resistant surface Industrial Machinery Co. (*Iron Age*, 1960, **185**, April 21, 160) A process that increases the life of screw conveyors five times is described. It involves spraying the screw with a paste containing chromium boride crystals and then applying an oxy-acetylene flame. An extremely hard alloyed surface results.—D.L.C.P.

Bright chromium plating and hard chroming: the French technique of chroming by diffusion P. Galmiche (*Corros. Anticorros.*, 1960, **8**, Feb., 49–58) The thermal chromizing processes developed at ONERA, with details of different cases and a number of connected or complementary treatments, are described.—S.H.–S.

Effects of Fe-Al powder in aluminium-diffusion coating S. Ueda (*Waseda Univ., Rep. Casting Res. Lab.*, 1958, (9), Nov., 65–70) [In English] The degree of packing of the powder, in the range 2–3 g/cm³, has little effect on coating properties. Beyond five repetitions of use, the diffusion effect of the powder is reduced (change of size). The optimum powder size is 60 mesh, and practical powders should have a max. content at this size.—K.E.J.

Reinforcing [a shaft] by oxy-acetylene sprayer metallisation R. Hubert (*Soudage*, 1958, **12**, (10), 206–207) A summary of tests of resistance to wear and conclusions. (Nov., 181–186) A study of the metal deposited by spray, following a brief statement of the theory of metallization, is succeeded by considerations relative to reinforcement of a shaft, resistance to tension, or torsion, with a description of a series of hardness tests.—S.H.–S.

Atomized ferro-tungsten for hard-facing electrodes S. Pilárik (*Zváranie*, 1960, **9**, (2), 40–41) An alloy containing 66%W, 32%Fe, and about 0·5%C is atomized from the melt by means of air (RZ method) to give 0·1 mm dia. particles for the production of hard-facing electrodes. The method is highly productive; from one 30 kg melt it is possible to obtain within one min. 18–21 kg of FeW powder with a particle size of less than 0·2 mm, i.e. 60–70% of the atomized metal consists of fine particles.

Production of two-layer steel sheet M. I. Bazhenov–Korchemny and P. N. Mazurik (*Metallurg*, 1959, (12), 23–24) A process developed at the Kuznetsk Metallurgical Combine is described for the production of two-layer steel sheet between 5–50 mm thick, 1 000–1 500 mm wide, and 2 000–7 000 mm long. The cladding layer is 0·5–5 mm thick. The maximum weight per sheet is 1 200 kg and it is made of ordinary and alloy steels.

The fabrication of stainless clad steel plates J. E. Roberts (*Weld. Met. Fabr.*, 1960, **28**, March, 97–102) Methods of production, cutting, cold and hot forming, and welding procedures are described; and stress relief and finishing operations are discussed.—S.H.–S.

POWDER METALLURGY

Blender-dryer reduces handling. Combination unit speeds preparation of powdered metals (*Iron Age*, 1960, **185**, March 31, 157) The equipment described is a self-contained unit for preparing tungsten carbide powder for pressing or for similarly treating other powdered metals. The main vessel is a V-shaped cylinder, with a liquid-dispersion pipe on its axis and surrounded by a heating jacket; it is also equipped with a vacuum take-off system. In a typical application the dry powders are blended and a lubricant solution is added and mixed in until granulation takes place; the mix is then vacuum dried.—D.L.C.P.

The influence of the oxygen content on some of the properties of iron- and copper-powder W. Rutkowski (*Hutnik*, 1960, **27**, (3), 105–108) The author is concerned with the effect of oxygen on the sintering of powders. Oxygen

can be introduced into the powder in two ways, by oxidizing the powder or by mixing in oxides. The author is concerned with the second method and discusses the effect of oxygen during sintering on hardness, electrical conductivity, toughness in bending, and density. The most satisfactory results were obtained with oxygen present as 4% of CuO or Fe_2O_3. Both methods give generally similar results.

How to specify powdered metal parts E. Gleixner (*Prec. Met. Mold.*, 1960, **18,** April, 36–39) The problem of specifying powdered metal parts is simplified if the differences between these and solid metal specification are considered. These are (1) the composition of a powdered metal part is not limited by the solubility of one metal in another, (2) a powdered metal part does not have a particular sintering temp. comparable with the definite melting point of a solid, (3) the density of a powdered metal part is variable. Advice is given on various aspects of specification.

The effect of copper on the carburizing of iron–copper alloys in sintering V. K. Sorokin (*Metalloved. Term. Obra. Met.*, 1959, (10), 61–62) Experimental findings show that when sintering at 1120° without any holding time, the carbon concentration is practically independent of the Cu content. By holding for 30 min, the carbon concentration changes hardly at all with up to 4%Cu, but further increases in the Cu content reduce carbon concentration. Similar effects have been noticed when sintering with a holding time of 60, 90, and 120 min.

Growth of porosity in sintering of iron–copper mixtures V. K. Sorokin (*Izvest. VUZ Chern. Met.*, 1959, (8), 101–103) In sintering Fe–Cu mixtures above the melting point of Cu, porosity develops in the specimens. The greatest increase occurs with 8%Cu. The porosity is due to the rapid one-sided diffusion of the molten Cu into the iron.

A sintering takes a big load (*Prec. Met. Mold.*, 1960, **18,** April, 40) A description is given of the manufacture of a tiny sintered part from an iron, copper carbon mixture, and used as a plunger thrust button in a diesel fuel injection pump. This saves the trouble of machining 'buttons' from stock.

FERRITES, CARBIDES AND CERMETS

Phase equilibria in the ferrite region of the system FeO–MgO–Fe_2O_3 A. E. Paladino (*J. Amer. Ceram. Soc.*, 1960, **43,** April, 183–191) Phase equilibria have been investigated up to 1300°C over an O_2-pressure range of 1·0 to 0·01 atm with five important features: (1) the spinel phase can exist with a deficiency of oxygen in high Mg-compositions; (2) Mg^{++} replaces Fe^{++} in Fe_3O_4 beyond the 'stoichiometric $MgFe_2O_4$', corresponding to the formula $(MgO)_x MgFe_2O_4$, where $x = 0{\cdot}092 \pm 0{\cdot}004$ and is independent of temp.; (3) the spinel field does not include a single-phase composition corresponding to $MgFe_2O_4$; (4) the lattice constant of spinels in this system depends on cation distribution, and the extent of distribution changes as a function of temp. which in turn depends on the Mg concentration in the spinel; (5) the spinel field has little or no width near its terminus.—S.H.-S.

Phase relations in the system iron oxide–Cr_2O_3 in air A. Muan and S. Somiya (*J. Amer. Ceram. Soc.*, 1960, **43,** April, 204–209) The quenching method has been used to determine approximate phase relations. Only two crystalline phases, a sesquioxide solid solution (Fe_2O_3–Cr_2O_3) with corundum structure, and a spinel solid solution (approx. FeO.Fe_2O_3–FeO–Cr_2O_3), occur in this system at conditions of temp. and O_2 partial pressure (0·21 atm.) used in this investigation. Liquidus temp. increase rapidly as Cr_2O_3 is added to iron oxide, from 1591°C for the pure iron oxide end member to a maximum of approx. 2265°C for Cr_2O_3. Spinel (ss) is the primary crystalline phase in iron oxide-rich mixtures and sesquioxide (ss) in Cr_2O_3-rich mixtures. These two crystalline phases are present together in equilibrium with a liquid and gas ($pO_2 = 0{\cdot}21$ atm.) at approximately 2075°C.—S.H.-S.

Phase diagram and dissociation characteristics in the ferrite region of the system Zn–Fe–O at the oxygen pressure of the atmosphere T. Yamaguchi and T. Takei (*Sci. Papers Inst. Phys. Chem. Res.*, 1959, **53,** Sept., 207–215) [In English] The investigation described was made in the temp. range 1000–1400°C. Mechanism of the dissociation observed in the two-phase system ($ZnFe_2O_4 + Fe_2O_3$), and the dissociation characteristics of various compositions are discussed.

Properties of high-temperature ceramics and cermets S. M. Lang (*Nat. Bur. Standards Monograph* 6, 1960, March 1, pp.45) Measurements of elasticity and density at room temp. are reported.

Considerations on sintering with special reference to oxides used in the manufacture of ceramic cutting tools M. Gion (*Met. Ital.*, 1960, **52,** March, 120–127) A summary is given of different theories advanced to explain the sintering process. The process of agglomeration of solid powdered materials either in the compression or failure stage is examined. The increase in porosity and cohesion during sintering, the role of mineralizers and the influence of the sintering atmosphere are described. The article stresses the importance of factors such as grain size, temp., time, and sintering pressure. Ceramic cutting tools are now as much an industrial reality as traditional metal cutting tools.

PROPERTIES AND TESTS

Why metals break and what to do about it D. Peckner (*Mat. Design Eng.*, 1960, **51,** April, 127–142) This is a summary of present knowledge concerning the fracture of metals including current theories of fracture, practical instances of fatigue and brittle failures and tensile and stress corrosion failures.

Fabricating qualities of pre-finished metals F. P. Romanoff (*Met. Fin.*, 1960 **58,** Feb., 55–62) A dynamic ductility ball penetration test (ASTM Standard for rolled zinc B–69–39) is used to determine the effects of copper, nickel, chromium, and brass electrodeposits on the forming properties of steel sheet. Ductile brass, copper, and nickel deposits, buffing, and ageing of non-buffed deposits generally improved the depth of draw. The thickness of ductile layers did not affect the properties. Non-ductile deposits reduced the ductility to less than that of unplated steel and the deterioration increased with deposit thickness. Chromium up to 50×10^{-6} in. in thickness did not embrittle deposits of ductile nickel on low-carbon steel.—A.D.H.

On the measurement of the tendency to residual stresses in castings D. Fortino (*Fond. Ital.*, 1960, **9,** (3), 89–94) A test-piece has been studied to determine the tendency to residual tensions in the iron. This bar was sensitive to certain factors—tapping temp., time in the mould, chemical composition, and heat treatment—which may cause residual stresses in the casting. The application of the law of cooling is studied and also the process of forming the residual tensions showing the role of the structural transformation Ar_1 in the iron. Maximum norms for the use of the test piece are indicated.

Studies on the cracking and on the residual stresses of forged crankshafts G. Altmeyer and A. Peiter (*Werkstattstechn.*, 1960, **50,** May, 274–278) In the manufacture of die-forged crankshafts a certain proportion of the shafts cracked during or after heat-treatment. Investigation of these defects showed that they were caused by a simultaneous occurrence of extremely high residual stresses and stresses imposed by the heating for the heat-treatment, in other words the shafts were too quickly cooled after forging and too quickly heated in the reheating furnace. Once the causes were found this treatment was avoided and no more cracks were found.—T.G.

Some observations on the variation of Young's modulus in cast iron M. Russenberger (*4th Annual Meeting, Inst. del Hierro y del Acero*, 1959, ref.A20, pp.6) [In Spanish] Methods of determining the static and the dynamic modulus are reviewed and the results discussed.

Investigating metal flow and determining the friction coefficient in the shrinkage of wedge-like specimens N. M. San'ko (*Izvest. VUZ Chern. Met.*, 1959, (10), 57–62) The contact surface during shrinkage of wedge-like specimens has three zones; the fixed zone, the friction zone, and the zone of slipping. (According to Unksov's terminology, '*Engineering Methods of Calculating the Forces in Pressure Working of Metals*', Mashgiz, 1955.) Experiments regarding the shrinkage of wedge-like specimens have not confirmed the theory that the zone of adhesion increases with increasing deformation. A method is proposed for calculating the friction coefficient for these wedge-shaped specimens.

On the mechanism of the internal friction peak of interstitial atoms in the face-centred cubic crystal Tsien Chi-tsiang (**Acta Met. Sin.*, 1959, **4,** (1), March, 69–74) Relationship between carbon content and height of the internal friction peak in 18·5%Mn steel was determined, with a parallel investigation for carbon diffusion in pure Ni. It is shown that the intersection of axes indicating solubility of C in the steel exists; the state of the carbon atoms can be modified by the addition of alloying elements. The internal friction peak in the Mn steel is shown to be due primarily to the rotation of a C–Mn atom pair (13 refs).

The toughness of metals B. H. d'Entremont (*Mét. Const. Méc.*, 1960, **92,** (5), 331–333) The beginning of an important paper on the theory of stresses. Internal stresses in solid bodies and their calculation by means of Mohr's circle are explained.—S.H.-S.

The toughness of tempered martensite D. Hardwick and K. R. Pirt (*JISI*, 1960, **196,** Nov., 301–308) [This issue].

Investigations on the activity of the carbon in crystallized binary and ternary iron carbon alloys H. Schenck and H. Kaiser (**Arch. Eisenhütt.*, 1960, **31,** April, 227–235) Investigations on the equilibria of Fe–C alloys with CH_4–H_2 and CO–CO_2 mixtures are described and compared critically with published results, on the activity of dissolved C in austenite. Experiments at reduced H_2-partial pressure showed no influence of dissolved H_2 on C activity. The influence of dissolved O_2 was demonstrated, and determined quantitatively; it displaces C from solution. The effects of Al, Ni, and Cr on the activity of dissolved C in Fe–Al–C, Fe–Ni–C, and Fe–Cr–C alloys respectively are examined. Al increases the solubility of C in austenite, Ni reduces it, and no conclusive results were obtained in the case of Cr (39 refs).

Solubility of carbon in liquid manganese in the presence of iron and silicon B. P. Burylev (*Izvest. VUZ Chern. Met.*, 1959, (6), 9–14) In view of the publications of Turkdogan, Hancock, and Herlitz in 1956 (*JISI*, **182** 274–277, **183,** 69–72), the author's earlier findings (this *J.*, 1958, (1), 83–93) are corrected and figures given for the solubility of carbon in the systems: Mn–C; Mn–Fe–C; Mn–Si–C; and Mn–Fe–Si–C. The calculated values correspond to experimental results for a content of 15%Si in these alloys.

Solubility of carbon in iron–sulphur melts M. Ohtani and N. A. Gokcen (*Trans. Met. Soc. AIME*, 1960, **218,** April, 380–381) An investigation of the effect of sulphur on the solubility of carbon at various temp. and concentrations was carried out in independent investigations. For any chosen sulphur concentration the solubility of carbon reported by one team was considerably lower than the other. The results of a reinvestigation of the problem are described.

Influence of tungsten on the activity of sulphur in molten iron A. Adachi and Z. Morita (*Tech. Rep. Osaka Univ.*, 1959, **9,** March, 147–152) [In English] Using the carbon tube-resistance furnace and the gas bubbling technique the equilibrium ratio between sulphur in Fe–S–W ternary molten iron alloy and H_2–H_2S gas mixture was established at 1600°C and 1650°C for S and W concentrations of up to 5% and 20% respectively and the influence of W on the activity of S in molten iron was determined at the experimental temp. The results showed that the activity of S in molten iron increased slightly in the presence of W and its influence was not so noticeable as that of C and Si.

Activity of dissolved phosphorus in molten iron G. Urbain (*Rev. Mét. Mém. Sci.*, 1959, **56,** Oct., 529–547) It is shown that the liquid Fe–P alloys possess activity coefficients independent of composition, up to 4%P. Above this, the P activity increases very rapidly (23 refs).

Bending and torsion of cold drawn wire F. Braas, F. Fischer, and H. Sedlaczek (*Stahl Eisen*, 1960, **80,** July 7, 936–942) This study was carried out with the aim of arriving at a standard test for the appraisal of wire and galvanized wire, in particular the bending and torsion index as a function of the total reduction in area and of the galvanizing operation. The results obtained are presented in many graphs. The interrelationships between the various factors are too complex as to allow a straightforward appraisal. This applies particularly to the heat of deformation, i.e. the testing speed must also be specified (35 refs).

Steel tubes cold-banded U. Bellometti (*Acier Stahl Steel*, 1960, **25,** July–Aug., 333–338) Banded pressure tubes are reviewed with the results of tests and destruction.

Reproducibility of impact tests D. E. Driscoll (*Proc. Ind. Tech. Conf. on Metals Processing*, 16–17–18, 1957, Oct.; *PB* 151308, pp.5) The results of a survey of a number of firms showed the impact test to be unreproducible. After improvements were made to the testing procedure and to faulty testing machines, reproducible results can now be obtained to an accuracy of ±5%.—R.D.

Impact properties of medium carbon steels as affected by boron, rare earths, and selected alloying elements R. E. Stiles and M. B. Pierson (*WAL TR* 325/1; *AD*-216459; *PB* 142426, 1959, June, pp.35; from *US Govt. Res. Rep.*, 1959, **32,** Oct. 16, 500) Impact properties of 18 medium carbon steels varied by rare-earth, and boron additions, and by alloy modifications are given. After full martensitic quench, steels were tempered in range 400° through 1200°F, and tested at room temp. and −40°F. Medium carbon steels with decreased Ni contents offset by increased Mn contents and with carbon, Cr, and Mo contents constant were found to be equally tough. Rare-earth and boron additions had no significant effect on impact properties.—S.H.-S.

Correlation of selected subsize Charpy bars: V. Standard Charpy bar C. H. Curll and G. M. Orner (*WAL TR* 112/91; *PB* 138548, 1958, May, pp.16; from *US Govt. Res. Rep.*, 1959, **32,** Oct. 16, 498) As means of impact acceptance testing of specimens from thin sections, a study was made of Charpy V notch impact properties of steels over temp. encompassing transitions from ductile to brittle behaviour. Test data reveal non-linear relationship between energy required to fracture standard-size and given subsize V-notch Charpy specimens outside transition temp. range for steels investigated.

Normalization procedures for NRL drop-weight test P. P. Puzak and A. J. Babecki (*NRL Rept.* 5220; *PB* 151114, 1958, Nov., pp.22; from *US Govt. Res. Rep.*, 1959, **31,** Feb.13, 102) The development of standard test conditions in the NRL drop-weight test and their effectiveness are discussed. Test data for 90 steels are presented, and procedures for a determination of surface strain in the test are explained in terms of the weld crack-opening developed in specimens tested at temp. approximately 100°F above the NDT temp.

Simple laboratory bulge tests for sheet-metal fracture transition studies and weldment performance evaluation P. P. Puzak and J. Stoop (*NRL Rept.* 5347; *PB* 151771, 1959, Aug., pp.18; from *US Govt. Res. Rep.*, 1959, **32,** Nov. 13, 620) A simple and inexpensive fracture test, based on the use of rubber as non-compressible fluid for transmitting the force of an impact blow to 6-in. square specimens, with simple equipment and suitable for use by skilled or semi-skilled technicians enabling them to evaluate rapidly numerous samples over wide range of testing temp.—S.H.-S.

Processes occurring on driving bolts into steel K.—A. Ebert and W. Hofmann (*Arch. Eisenh.*, 1960, **31,** March, 145–151) The structure of the bolt and surrounding material obtained by firing hardened steel bolts into steel, the depth of penetration of the bolts and their adhesion were examined, and the influence of bolt geometry, and the effect of heating the steel test blocks were investigated (11 refs).

Basic research into metal fatigue (*Met. Treatment*, 1960, **27,** Feb., 50–52) A summary of a discussion outlining the boundaries of present knowledge of fatigue and suggesting further lines of work. These include the application of dislocation etch-pit techniques, study of the effect of cyclic stress on interstitial atoms, micro-internal stresses and micro-plasticity analysis.—A.H.M.

Research on ferrous materials fatigue H. N. Cummings, F. B. Stulen, and W. C. Schulte (*WADC-TR* 58–43; *AD* 155772; *PB* 151243, 1958, pp.115; from *US Govt. Res. Rep.*, 1959, **31,** Jan. 16, 39) Three studies of the effect of fatigue stressing on steel R. R. Moore rotating beam specimens were made: (1) rate of propagation of fatigue cracks, (2) effect on fatigue strength of surface hardening by shot peening and plating, by carburizing and nitriding, and (3) the transverse properties of SAE 4340 steel. An equation is proposed expressing fatigue crack length as a function of fatigue life. Increased strength by surface hardening is indicated and limitations on use of Prot method testing are discussed. Decrease in transverse strength as compared with longitudinal strength is revealed and discussed for rolled and forged SAE 4340 steel.—S.H.-S.

Qualitative aspects of fatigue of materials H. N. Cummings (*WADC Techn. Rep.*, 59–230; *PB* 161145, 1959, Sept., pp.250) An extensive discussion with a review of theories of the mechanism of fatigue. Testing is described and much of the report deals with steel and the efforts of heat and mechanical treatments as well as environmental conditions.

Statistical evaluation of data from fatigue and creep-rupture tests. Part I. Fundamental concepts and general methods W. Weibull (*WADC Techn. Rep.*, 59–400, Part 1; *PB* 161297, 1959, Sept., pp.73) A review presenting a classification into three types (short, medium and long life tests) with notes on computation methods and the fitting of curves to observations.

Considerations relating to the development of fatigue testing machines H. Oschatz (*Materialprüfung*, 1960, **2,** April 20, 129–134) Development tendencies with respect to increased efficiency, improved measurement techniques, and greater economy in effort and cost are discussed with examples (11 refs).

A contribution to the study of the fatigue strength of parts repaired by building-up processes H. de Leiris and H. Granjon (*Soudage*, 1960, **14,** March–April, 85–101) A report on cyclic torsion tests of 50 mm diameter cylindrical bars of 50–60 kg/mm² built up by (a) arc welding with coated electrodes, or (b) by metal spraying, and machined after the building-up operation. In (a) a study was made of various thicknesses, widths, and welding conditions; in (b) several methods for the preparation of the part to be built up were considered.—S.H.-S.

Investigation of fatigue properties at room temperature of high-strength steels having high tempering temperatures H. N. Cummings, F. B. Stulen, and W. C. Schulte (*WADC Techn. Rep.*, 59–227; *PB* 161144, 1959, Sept., pp.95) Steels for general use, for springs, for surface or space vehicles, and for bearings were examined. Fatigue performance should be improved by lowering inclusion content and restricting the size of inclusions to <0·0005 in.

Accelerated fatigue testing—a new technique for determination of fatigue limit under progressive loading P. K. Das (*J. Inst. Eng. (India)*, 1960, **40,** Jan., 205–217) A modified and simplified Prot method is described from which the fatigue limit can be determined from two tests.

Influence of temperature on the crystalline behaviour of iron after deformation by alternating torsion J. de Fouquet (*Publ. Sci. Techn. l'Air*, 1959, (N.T.81) pp.108) Micrographic, X-ray and tests of hardness, tensile strength, and torsion, were used to study stages of fatigue. The mechanism of fatigue is discussed in the light of the results.

The information obtainable from single- and multi-stage fatigue tests. I. Single-stage tests E. Gassmer (*Materialprüfung*, 1960, **2,** April 20, 121–128) The historical development of the Wohler method is outlined, illustrative examples are described, with particular reference to the testing of structural members, and requirements to be met by testing equipment are outlined briefly (22 refs).

The effect of size and notch sensitivity on fatigue characteristics of two metallic materials: Part I, aluminium alloy 755-T, part II, S.A.E. 4340 steel H. F. Moore, T. J. Dolan, and B. C. Hanley (*AF Techn. Rep.* 5726; *ATI* 36961; *PB* 140862, 1948, Oct., pp.161; *Progress Rept. No.*6, Oct., 48, pp.161; from *US Govt. Res. Rep.*, 1959, **32** Sept. 11, 361) The steel was heat-treated to 160 000 psi. Decreased reversed bending fatigue strength was found with increase in test piece dia. from ¼ to 1¾ in.; notch sensitivity tended to increase with size.

Studies of the effect of dynamic preloads on the mechanical properties of steel R. C. Smith (*NRL Rep.* 5323; *PB* 151685, 1959, May, pp.15; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 368) Results are reported of testing a low-C steel under dynamic loads of varying intensity in an adaptation of the Taft–Pierce shock machine for electronic devices. Specimens were then aged at 68–250°F and re-tested.

Study of the deformation of fatigue specimens by residual-stress determination G. Altmeyer and A. Peiter (*Materialprüf.*, 1960, **2,** June, 198–207) It was found from the *S/N* curve of fatigue specimens that the specimens fail when the residual stresses imposed by compression before the test are disappearing, in particular when they have reached a minimum at the edges. The limitations of the method are discussed. The tests are described in detail and the results presented in many graphs (25 refs).

Investigations of the shape of the Wohler curves and the damage curves of steel wires M. Hempel (*Arch. Eisenh.*, 1960, **31,** June, 373–383) The behaviour of various types of steel wire with different pretreatments was investigated under alternating bending stresses, and the Wohler and damage curves were derived and the results discussed (22 refs).

Study of stress properties by rotary flexion of various qualities of forged and cast constructional steels made in the electric steelworks of ARBED at Dommeldange P. Wagener (*Rev. Tech. Luxembourg*, 1960, **52,** April–June, 69–79) [In French] This second article in the series compares the performance and properties of various heat-treated and case-hardened Cr–Ni steels under stress giving the fatigue limits.

Effect of hardness, surface finish and grain size on rolling contact fatigue life of M-50 bearing steel R. A. Baughman (*Trans. ASME, J. Basic Eng.*, 1960, **82,** June, 287–294) The effect of hardness, surface finish, and grain size upon the compressive rolling contact fatigue strength of M-50 bearing steel has been studied. Considerable testing on the RC rig and statistical treatment methods have been included. A mathematical expression relating these variables to life expectancy is presented and the optimization of these variables is discussed. It is shown that the bearing fatigue of M-50 increases with increasing grain size. The optimum life occurs at R_c64 hardness, 1·5 rms surface finish, and a grain size of ASTM 2.

Radiographic investigation of the processes leading to the destruction of steel specimens by tension-compression cyclic stressing. Part I P. Müller and E. Macherauch (*Arch. Eisenh.*, 1960, **31,** March, 161–171) A detailed description of the equipment and test pieces used is given, by which a complete analysis of the lattice strain condition in the polycrystals of the surface layers of specimens subject to tension–compression cyclic stressing is possible This analysis is carried out, and its possible applications and limitations discussed (34 refs.)

Effect of oleophobic films on metal fatigue H. E. Frankel, J. A. Bennett, and W. L. Holshouser (*NBSJ Res.*, 1960, **64C,** April–June, 147–150) A low-alloy steel showed increased fatigue resistance on coating with polar organic compounds (alcohols and primary amines). With 17-7 PH steel little effect was observed.

Fatigue of metals by thermal stresses H. G. Baron (*New Sci.*, 1960, **7,** May 19, 1282–1289) Cracking in alloy steel and non-ferrous metals is illustrated and discussed.

Comparison of fatigue behaviour of leaded and non-leaded AISI 4340 steel at high hardness levels J. R. Suhre and G. W. Brock (*T. & A. M. Rept. No.* 570; *PB* 140986, 1959, Feb., pp.45; from *US Govt. Res. Rep.*, 1959, **32,** Oct. 16, 497–497) Pb additions had slight effect on tensile properties of material. Mean fatigue limit of smooth specimens was

decreased slightly at all strength levels above 103000 psi. Pb additions did not substantially affect fatigue life of specimens tested at stress levels above mean fatigue limit.—S.H.-S.

Development of ultra-high strength temper-resistant steels designed for improvement of fatigue properties through relief of residual stress H. B. Nudelman and J. P. Sheehan (*WADC Techn. Rept.*, 59–86; *PB* 151971, 1959, June, pp.32; from *US Govt. Res. Rep.*, 1959, **32,** Nov. 13, 620) Various alloy steels were investigated, Mo being the major element used for improving temper resistance in steels having 0·30–0·55%C. Cr, V, and W were used in minor amounts. Austenitizing at 2200°F was required to dissolve all the carbides and provide a fully martensitic structure upon oil quenching or air cooling. Alloys were developed capable of maintaining hardnesses of Rc40 to Rc59 after tempering for 1 h at 1250–1300°F.

A study of the nonlinear theory of creep Chao Tsu-wu (*Sci. Sinica*, 1960, **9,** May, 652–663) [In English] A new basic equation without a t variable is proposed. Relaxation and pure bending are investigated.

Creep rupture tests for design of high pressure steam equipment E. A. Davis (*Trans. ASME, J. Basic Eng.*, 1960, **82,** June, 453–461) Creep rupture tests on tubular specimens of type 316 stainless steel were run at 1200°F and at pressures up to 24000 psi. The specimens were tested under internal pressure and equal biaxial tensions. The results of these tests correlate favourably with those of uniaxial tension tests if a comparison is made on the basis of effective stress and effective strain rate.

Steady creep of a tube under combined bending and internal pressure I. Finney (*Trans. ASME, J. Basic Eng.*, 1960, **82,** June, 462–473) It is shown that for a tube in bending the steady state bending creep rate may be greatly increased by the addition of internal pressure. If the maximum bending stress is small compared to the pressure stress a very simple expression is obtained for the ratio of bending creep rates with and without internal pressure. Experiments on lead tubes show good agreement with this theory.

Apparatus for measuring creep deformation E. Pouillard (*Rev. Mét.*, 1960, **57,** March, 247–252) A description of the design and results obtained with the equipment developed by the author (the ERM 59 F apparatus). The loading system, furnace, and extensometer are described.

Phenomenological theories of time effects in metals at high temperatures with special reference to primary creep B. C. Hoskin (*Nonr*–526 (20)/7; *PB* 142075, 1958, Sept., pp.31; from *US Govt. Res. Rep.*, 1959, **32,** Oct. 16, 499) Several laws suggested as adequate for describing mechanical behaviour of a metal at high temp. are reviewed, attention being confined to case of constant ambient temp. and uniaxial stress systems, and most consideration being given to question of a law describing the deformation associated with so-called primary creep.—S.H.-S.

Compressive strength and creep of 17-7 PH stainless-steel plates at elevated temperatures B. A. Stein (*TN* 4296, 1958, July, pp.33; from *US Govt. Res. Rep.*, 1959, **31,** Jan. 16, 39) Compressive strength test and compressive creep test results are presented. Test results are compared with plate strengths and creep failure stresses determined from semiempirical approximations.—S.H.-S.

Transgranular and intergranular fracture of ingot iron during creep L. R. Shepard and W. H. Giedt (*TN* 4285, 1958, Aug., pp.26; from *US Govt. Res. Rep.*, 1959, **31,** (1), 43) Creep tests performed on ingot iron at 700–1350°F indicated that intergranular fracturing may occur without grain-boundary shearing, in a lower temp. range. It was concluded that a vacancy-condensation mechanism is probably responsible for high-temp. intergranular fracturing in ingot iron.—S.H.-S.

Prediction of creep failure time for pressure vessels F. P. J. Rimrott, E. J. Mills, and J. Marin (*Trans. ASME, J. App. Mech.*, 1960, **27** June, 303–305) The creep-failure time for a thick-walled pressure vessel is defined as the time at which the creep strain reaches infinity. It was then shown that the creep failure time defined in this manner can be used to predict the time to fracture of a vessel. The solution is presented in the form of graphs. Simplified formulae for creep failure time were obtained both for thin-walled cylinders and very thick-walled cylinders. The latter results appear as asymptotes to the curves for the exact solution of the thick walled cylinder.

Materials—property—design criteria for metals. Part 8. The creep behaviour of selected materials in the range up to 1% net creep strain and 1000 hours R. J. Favor, W. P. Achbach, and H. J. Grover (*WADC Techn. Rep.*, 55–150, Part 8; *PB* 161302, 1959, Sept., pp.23) Airframe materials are considered. Stainless steels are included.

Effect of prior creep on short-time mechanical properties of 17-7 PH stainless steel. (RH 950 condition compared to T.H. 1050 condition) J. V. Gluck and J. W. Freeman (*WADC Techn. Rep.*, 59–339; *PB* 161296, 1959, Oct., pp.82) Tests for 10, 50, and 100 h unstressed or stressed up to 2% creep at 600, 800, and 900°F were made. Loss of ductility was observed after creep in the RH 950 condition. A considerable Bauschinger effect was observed after creep at 600°F. Other phenomena are noted.

Correlations between transverse and torsional shear creep deformations J. Marin (*WADC Techn. Rep.*, 57–755; *PB* 161258, 1959, June, pp.26) Tests on rivets are reported. Correlation of the shear modes is developed and from the theory creep deflection can be obtained from the constants for pure shear and simple tension.

Contribution to the theory of the formation of waviness of railway rails G. Beck (*Stahl Eisen*, 1960, **80,** July 21, 1029–1031) The formation of waviness of railway rails has recently been attributed to stick-slip sliding. The author presents a mechanical analogue for waviness formation on this principle and discussed its working. He then deals with the theory of Derjaguin, Push, and Tolstoi and concludes with the requirements that must be fulfilled for avoiding waviness formation.—T.G.

The causes of chipping and transversal cracks in rail heads L. M. Shkol'nik (*Stal'*, 1960, (6), 555–558) Chipping is shown to be due to internal fatigue cracks coming to the surface. Non-metallic inclusions promote their formation. It may also be due to small scale-like overflows in the work-hardened metal or by cracking of too thin a hardened layer. Other types are distinguished and their causes discussed. Increased hardness and penetration of the hardened surface layer for at least 20–25 mm is recommended.

Instability of steel bottoms in waste storage tanks L. E. Brownell (*HW*–57274, 1958, Aug., pp.26; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 405) [No abstract].

Vickers hardness tests on curved surfaces H. G. Harper and F. W. Rabarts (*Machinery*, 1960, **96,** June 1, 1238–1240) The necessary correction factors are evaluated.

Industrial standard of accuracy in diamond-pyramid indentation hardness measurement J. F. Kayser and Testing and Measurements Committee of Inst. Sheet Met. Eng. (*Sheet Metal Ind.*, 1960, **37,** March, 173–183, 202) This is the second report and deals mainly with the accuracy of reading the hardness impressions. The results of readings taken by 66 firms are given and analysed statistically, together with comments from the NPL. It is concluded that the variability arises from systematic differences between the observers.—A.H.M.

Note on the application of a hardness test to determine the quality of a spot weld on steel. IIW, Commission III (*Soudage*, 1960, **14,** 147) Instructions are laid down for the preparation of the specimen and the method (Vickers) for carrying out the test, and for presentation of results.—S.H.-S.

An improved microhardness tester for high temperature use J. H. Westbrook (*ASTM Bull.*, May, 53–58) Microhardness testing is often the only means of obtaining information on the temp. dependence of strength of hard, brittle materials. Design problems increase as more brittle materials are tested at higher tem. and lower loads. The design construction and operation of an improved high-temp. microhardness tester are described. Examples of various applications of the instrument are given to demonstrate its capabilities and the variety of problems for which it may be used.

Change of coercive strength in the ageing of low-carbon unalloyed steels M. Nacken and W. Heller (*Arch. Eisenh.*, 1960, **31,** March, 153–160) The progress of quench-ageing was followed by simultaneous measurement of damping and coercive strength, the materials tested being high-purity iron, Thomas steel, air-refined special steel, and mild electric steels. Measurements were made during ageing at temp. from 20 to 350°C, and after quenching followed by cold working. The influence of ageing temp., amount of dissolved C, density of nuclei, and size and distribution of precipitated carbides are examined, and the relationship between amount of deformation and coercive strength are examined (19 refs).

Stress induced strain ageing J. O. Brittain and S. E. Bronisz (*AFOSR TN*–58–369; *AD*–154275; *PB* 135370, 1958, June, pp.21; from *US Govt. Res. Rep.*, 1959, **31,** Feb. 13, 102) Experiments have shown that stress-induced strain ageing reaction in steel proceeds rapidly in the temp. range of 0 to 60°C. The variation of stress-induced strain ageing with plastic strain, ageing times, and temp. is reported. The activation energy/in^2 strain ageing was found to be 10000 cal/mol. Results are interpreted as dislocation pipe line diffusion of carbon.—S.H.-S.

Effect of stress-ageing treatment on the strain-ageing behaviour of mild steel T. Sakurai, T. Kawasaki, and H. Izumi (*Nippon Kinzoku*, 1959, **23,** April, 219–222) With 0·05%C mild steel specimens, strain-age hardening was much less after stress-ageing than when it was not applied. The tendency was enhanced by higher temp. or time of treatment. A non-ageing mild steel can be made by stress-ageing under appropriate conditions. The results are explained by a large reduction of solute atoms in ferrite. Stress-ageing may be used to prevent stretcher strains of deep-drawing sheet steels (12 refs).—K.E.J.

The mechanism of fracture and its application to engineering structures J. A. Kies, H. L. Smith, and G. R. Irwin (*Rev. Mét. Mem. Sci.*, 1960, **57,** Feb., 101–117) The nature of the processes of brittle fracture is discussed, and experimental analysis of the stresses governing crack propagation is described and discussed, and the influence of temp. and the geometry of the specimens are investigated. The order of magnitude of the force g tending to provoke the propagation of cracks, and the relation of this factor to the stress intensity K are discussed (27 refs).

Fracture mode transition for a crack traversing a plate G. R. Irwin (*Trans. ASME, J. Basic Eng.*, 1960, **82,** June, 417–423) The conclusions of these investigations are that the abrupt change from brittle to ductile fracture with increase of temp. as well as the less commonly studied change of fracture made with plate thickness can be ascribed to the unstable growth tendency of the plastic zone at the leading edge of the crack when conditions necessary for a crack edge stress environment of plane strain in central portions of the plate thickness are not present. Knowledge of values of α characteristic of selected readily observed features of the fracture within the region of a fracture mode transition permits an estimate of the value of Gc for completely plain strain fracturing.

Brittle fracture as the basic problem of local safety in structural engineering M. Marinček (*Materialprüfung.*, 1960, **2,** May, 157–160) A general discussion of the problem of brittle fracture in structural engineering with an emphasis on the validity of the Schnadt test.

The brittle fracture problem and the load carrying capacity of structures L. E. Benson and S. J. Watson (*Metallurgia*, 1960, **61,** April, 145–152) The problem of brittle fracture of steel is considered in relation to strength. Overloading may cause a brittle looking fracture but this does not necessarily imply lack of strength or ductility and it may give satisfactory service under normal loads. Information on the load which a structure can safety withstand would be much more useful than the results of conventional notch impact tests. Considerably more testing is required to assess

the dependence of strength on material, temp., size, and notch geometry.

Electrocapillary phenomena in the cast iron-slag system B. V. Patrov (*Izvest. VUZ Chern. Met.*, 1959, (6), 3–7) The specimens consisted of a cast iron containing 3·2%C; 2·0%Si; 0·65%Mn; 0·05%S, 0·36%P in contact with three synthetic slags containing each 37–45% of CaO and of SiO_2 and 18%Al_2O_3. The experimental method was explained in the collection of the Leningrad Polytechnic Institute of 1957, (188), 106. Electrocapillary curves given for each slag show a maximum for different values of polarization potential. The surface tensions at the interface between cast iron and N_2 have also been measured.

Silicon oxygen equilibrium in liquid iron S. Matoba, K. Gunji, and T. Kuwana (*Tetsu to Hagane*, 1959, **45,** Dec., 1328–1334) The equilibrium was studied at 1570, 1625, and 1680°C with Fe–Si alloys melted in SiO_2 crucibles in H_2–H_2O gas mixtures. Thermodynamic data are given for the equations $SiO_2(sat) + 2H_2 = \underline{Si} + 2H_2O$ and $SiO_2(sat) = \underline{Si} + \underline{2O}$, for the interaction parameter of $\underline{Si}$ in liquid Fe, the effect of Si on the activity coeff. of O in liquid Fe, and the activity coeff. of Si in liquid Fe (14 refs).—K.E.J.

Determination of the solubility of chromium oxides in iron slags O. A. Esin and I. N. Zakharov (*Izvest. VUZ Chern. Met.*, 1959, (10), 9–16) The emf method described (1958, (11), 45–52) was used to assess the effect of iron oxide additions (up to 30%) on the solubility of chromium oxides in the molten slag of initial composition 50%CaO, 35%SiO_2, 8%Al_2O_3, and 7%MgO. It has been shown experimentally that the theoretical equations for regular ionic solutions with correction for polymerization describe adequately the available experimental data and may be used for approximate calculations of the Cr_2O_3 solubility in liquid slags of different compositions.

A method for determining the yield stress of steels from the shear hardness K. Waitzmann (*Hutn. Listy*, 1960, **15,** (1), 25–29) A method was developed and tested which facilitated the evaluation of the yield stress without the use of tensile specimens or tensile tests. A simple relation between the yield stress and the hardness obtained by means of a spherical indenter in which a steel ball is pressed into the metal at a point where a cylindrical cavity of radius smaller than that of the sphere has been drilled, is established. The significance of the correlation is discussed.—P.F.

Deformation of mild structural steels under static load F. Althof, D. Böhm, and F. Erdmann-Jesnitser (*Metalloved. Term. Obra. Met.*, 1959, (10), 6–16) It is not possible with methods in current use to detect any appreciable effect of the static tensile stress on deformation ageing, but with other methods this becomes possible. Thus Seeman and Siol (*Acta Metallurgica*, 1958, (6),) found that a load of 7·3 kg/mm² retards the hardening ageing and Shenk and Schmidtman (*Archiv. Eisenhüt.*, 1954, (25)) found that dynamical stress speeds it up. Further investigations are, however, necessary before a complete explanation of the action of internal stresses can be given.

The effects of inelastic action on the resistance to various types of loads of ductile members made from various classes of metals. Part VIII. Eccentrically-loaded tension members made of two stainless steels tested at elavated temperatures O. M. Sidebottom, M. E. Clark, and S. Dharmarajan (*WADC Technical Report*, 56–330, Part VIII; *ASTIA Document No.*202495; *PB* 151673, 1958, Oct., pp.53) A theoretical and experimental treatment. In the latter, tests were made on 304 stainless steel at 1000°F and on 17–7 PH stainless steel at 1000°F and 1200°F, specimens being eccentrically-loaded rectangular-section members. The type 304 steel did not creep at 1000°F. The heat-treated 17–7 PH steel had higher strength than the untreated steel (the treatment being precipitation hardening), and was found to show a small amount of inelastic deformation at zero time but larger creep in 30 min. at 1000°F. The untreated 17–7 showed a small amount of creep at 1000°F and much larger creep at 1200°F.

Use of resistance strain gauges K. G. Mantle and E. Procter (*Engineer*, 1960, **209,** March 25, 527–528) Experience of an experimental stress analysis section of John Thompson Ltd is reported. The techniques developed are outlined.

The behaviour of steel sheet in forming by examining the results of the tensile test G. Chiuppani (*Ing. Mecc.*, 1960, **9,** March, 33–37) [In Italian] The tensile test can provide results from which the behaviour of sheet in forming where carried out properly can be determined. Good forming characteristics are defined by a low ratio S/R between the yield point and the UTS by a high elongation A and a low ratio of strain hardening ($r - s$)/C, r being the breaking strength and C the percentage reduction in area after breaking.

The strengthening of austenitic solid solutions F. Eberle, J. H. Hoke, E. J. Rozic, and W. E. Leyda (*WADC Techn. Rep.* 58–28; *ASTIA Doc. No.*151161; *PB* 131992, 1958, April, pp.60) Among vacuum-melted C-free ternary and quaternary alloys of Fe, Cr, Ni, and Co, the compositions 10Fe–20Cr–70Ni, and 20Cr–80Co, showed the highest 100-h rupture strength at 1800°F. It is shown that the former alloy responds most effectively to intermetallic compound hardening with Ti and Al, less so to complex carbide and not at all to solution hardening, while the latter alloy responds to all three methods.

The influence of heat treatment on the orientation of the line of slip in cold-rolled steel N. N. Davidenkov and E. I. Brainin (*Izvest. VUZ Chern. Met.*, 1959, (10), 79–87) The experiments described with 08kp steel with a degree of reduction of 75% have pointed to certain conclusions, among them that the anisotropy of slip in fractures is due to the fibrous structure, and the direction of the line of slip is determined by the rolling texture; that the recrystallization texture does not show appreciable slipping anisotropy either in the plastically deformed surface (Lüders lines) or in the fracture. The orientation of the Lüders lines in the recrystallized steel with almost equiaxial grains is determined only by the form of the stress conditions.

Testing of deep-drawing steel by torsion B. Otta and J. Teindl (*Hutnik*, 1960, **10,** (1), 10–13) Drawability tests by torsion, as proposed by Eisenkolb (*Stahl Eisen*, 1948, **68,** (43–46), were found to be more suitable than tests carried out on a press. Drawability is determined accurately, rapidly, and economically.—P.F.

Investigation of the strength of seamless and longitudinally welded tubes under alternating torsional stresses E. A. Cornelius (*VDIZ*, 1960, **102,** June 1, 645–650) The experimental arrangement is described in detail, the method of calculations worked out and the results discussed. Comparative tests on 11 St35.29 welded tubes and 11 St 35.8/1 seamless tubes indicated that the former gave better results. This is attributed to increased surface notch effects and greater variations in wall thickness. No cracks originated in the welded joints.

A new solution of the stress conditions in triaxial compression A. Balla (*Acta Techn.*, 1960, **28** (3–4), 349–388) [In English] The solution for a loaded cylinder is given.

A remotely-controlled drop-weight test machine for brittle-fracture studies L. E. Steele and J. R. Hawthorne (*NRL Report*, 5278, 1959, Feb. 18, *PB* 151500, pp.6) The equipment described was designed to study the notch impact properties of large steel specimens in relation to the effects of nuclear radiation. A free-falling weight delivers a fixed amount of energy to a temp.-controlled specimen, and the test is used to define the control temp. below which brittle fracture may be initiated in the presence of sharp notches or flaws.

Evaluation principles of notch-toughness. The testing of weldable carbon steel plates with special regard to low temperature notched-bar impact tests F. Cappelli and G. Testero (*Met. Ital.*, 1960, **52** March, 97–106) After a summary of present knowledge of brittle fracture in welded structures the principal methods of determining the notch sensitivity of steel are described. The article concludes with an examination of the results of tests carried out on weldable carbon steel plates.

Comparison of Charpy V-notch and drop-weight tests for structural steels J. H. Gross (*Weld. J.*, 1960, **39,** Feb., 59s–66s) Nine different melts of steel were tested in ten different conditions for both nil ductility transition temp. and various Charpy V-notch transition temp. in order to attempt to establish a correlation between the two types of test. The results are presented after statistical analysis, and the resulting correlations are discussed.

Cratering and shock wave phenomena in steel plates at high impact speeds E. B. Mayfield and J. W. Rogers (*J. Appl. Phys.*, 1960, **31,** March, 472–473) Impact of Al projectiles on steel plates at impact velocities of 2500–3000 m/sec. and about 1100 m/sec. was studied and crater volume and penetration were measured. Shock wave velocity from the free surface was determined and particle velocity calculated. For annealed 4130 steel plates impacted at 2750 m/sec. average velocity, average face surface particle velocity was 0·205 mm/μ sec. Existing theory on cratering and penetration was confirmed.

Stress induced strain ageing J. O. Brittain and S. E. Bronisz (*Trans. Met. Soc. AIME*, 1960, **218,** April, 289–294) Experiments have been carried out to study the effect of an applied stress on strain-ageing in steel. It was found that the stress-induced strain ageing reaction proceeds rapidly in the temp. range 0° to 60°. The variation of stress-induced strain ageing with plastic strain, ageing time, and temp. is reported. The activation energy for the stress-induced strain-ageing was found to be 10000 cal per mol for the steel used in this investigation.

Influence of work hardening on the structure and properties of heat resisting EI 437 alloy M. L. Bernshtein and Z. V. Svistunova (*Stal'*, 1960, (4), 358–362) EI 437 is a Ni–20·5%Cr alloy but its behaviour is here compared with that of 18–8 and 16–25–6 alloys.

Certain anomalies in the initial stage of plastic deformation Ya. R. Rauzin (*Metalloved. Term. Obra. Met.*, 1959, (9), 23–29) The experiments described show the great analogy between the different anomalies observed in the initial stages of deformation and this suggests that the cause of these phenomena is the mechanism of the deformation. The principal factor in this mechanism is the intergranular shift which changes with every stage of the deformation. In this respect, an increase in the degree of purity and in crystal size changes the intergranular displacement with fewer stages of deformation. (The three anomalies considered are: the effect of the purity of the metal and grain size; the possibility of a yield point elongation coincident with the critical degree of deformation; and the Bauschinger effect).

Properties of deep-drawing sheets and tests designed to select the best quality for use S. Di Bartolo (*Ing. Mecc.*, 1960, **9,** April, 17–23) Mention is made of the stresses and deformations which take place during drawing. Various defects of drawn pieces are examined and tests carried out on sheets are summarized. It is now possible to make a qualitative selection of sheets by accurate control of the production cycle and from the results of various tests, but it is difficult to preselect sheets of suitable quality for drawing. Reference is made to possible methods of solving this problem.

Microcracks and the static and dynamic elastic constants of annealed and heavily cold-worked metals J. R. Bristow (*Brit. J. App. Phys.*, 1960, **11,** Feb., 81–88) Sub-microscopic cracks in heavily cold-worked metals have been suggested in explanation of the very large discrepancies in dislocation densities estimated from changes in density and electrical resistivity and release of stored energy on annealing such materials. It is shown that microcracks will produce changes in the elastic constants of a material comparable with but somewhat larger than the change of electrical resistivity rather than with change in density. An unexpected result is a very large difference between the bulk moduli and Poisson's ratio determined statically and dynamically.

The effect of the sigma-phase on the mechanical properties of the heat resistant alloys E. E. Levin, E. M. Pivnik, and P. M. Libman (*Metalloved. Term. Obra. Met.*, 1959, (9), 17–19)

From an investigation of the 18–8 steel which contains the σ-phase, for the deformation failure mechanism between 650–800° *in vacuo* it was shown that σ-phase at high temp. has a sufficiently high plasticity. Hence the cracks occurring in the specimens investigated occurred at the austenite grain boundaries and spread into the grains. Under normal conditions the coarse σ-phase does not reduce the general plasticity of the material during deformation at high temp. either for short or for long duration of the tests.

The construction of the line of slip in steels N. S. Alferova, V. P. Konovalova, and A. I. Rizol' (*Izvest. AN SSSR OTN Metallurg. i Topl.*, 1959, (6), 131–132) During the plastic deformations of steel, considerable local distortions are found, and where these exceed their limiting value microfailures occur. These, with continued deformation, develop in the direction of slip. Under considerable external loads acting on the grains, the line of slip breaks the crystals up into blocks the boundaries of which are the intercepts of the line of slip.

Shake method tests iron pipe (*Iron Age*, 1960, **185,** April 7, 93) A technique for testing the fatigue life of the pipes in a matter of min is described. A 10 ft length of pipe is suspended at the node points, and vibrations are induced in it. Failure can be detected by a change in the natural resonance frequency, or by reduction of air pressure in the sealed pipe. The method is several times faster than other tests using cyclic bending.—D.L.C.F.

Development of a short-time fatigue testing method National Metallurgical Laboratory, Jamshedpur (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 27) A new attachment to the standard machine was produced for recording automatically the load deflection curve of the rotating beam under progressively increasing load. Results of operation of this machine compare favourably with conventional fatigue method and can profitably be used for ferrous materials.

Statistical interpretation of the results of fatigue tests A. Palazzi (*Rev. Mét. Mém. Sci.*, 1959, **56,** Sept., 403–416) A statistical study is reported of the results of fatigue tests at low, high, and mixed stresses, and the use of the graphs plotted to deduce fatigue properties without calculation is discussed.

Fatigue resistance of hot rolled steel in rods and plates with black surface I. V. Kudryavtsev, N. M. Savvina, and L. N. Burmistrova (*Metalloved. Term. Obra. Met.*, 1959, (12), 31–35) In smooth specimens a blank surface reduces erosion resistance by 15–24%. For plates and shafts which touch other components during operation, a black surface appreciably increases the long-term strength as compared with mechanically treated surfaces.

The effect of metallurgical variables on the fatigue properties of AISI 4340 steel heat treated in the tensile strength range 260,000–310,000 psi J. I. Fisher and J. P. Sheehan (*WADC Technical Report* 58–289; *ASTIA Document No.*208321; *PB* 151661, 1959, Feb., pp.144) The fatigue properties of eight heats of AISI 4340, melted so as to produce a variety of non-metallic inclusions, were studied in the range 260000–310000 lb/in² by the rotating beam method, using standard and cylindrical Moore specimens. A fairly good correlation was observed between the mean width of the largest inclusion and the ratio endurance limit/tensile strength, the ratio being inversely proportional to inclusion size. No effect of reducing the amount of retained austenite and dissolved H_2 and N_2 on fatigue properties was observed.

A study of fatigue failure in steels containing various amounts of carbon M. Klesnil (*Hutn. Listy*, 1960, **15,** (2), 120–125) Electronmicrographic and X-ray studies were carried out on normalized plain steels containing 0·09, 0·4, and 0·8%C. Above the fatigue limit damage develops in highly deformed ferrite grains in the surface. It takes the form of micro-cracks originating in slip bands. Spread of such cracks leads to eventual fracture. Some evidence of slip remains in bands even after these have been removed by polishing off a thin surface layer. This evidence is in fact also due to fine cracks.—P.F.

Using the relations between temperature and the parameters of long term strength N. N. Geminov (*Metalloved. Term. Obra. Met.*, 1959, (9), 19–22) The parameter relations of Larson and Miller (*ASME*, 1952, **74**) and of Manson and Harford (*NAGA Techn. Note*, 1954) are in principle more correct than those of Manson and Succop (*ASTM STP*, 1956, No.174) and of Graham and Walles (*JISI*, 1955, **179,** 105–120) but the variability of the coefficients requires much more attention in the case of these relations. The temp. relations log t − 1/T or log t − T are linear for long duration of service and may be used for constant loads to extrapolate for much lower temp.

The behaviour of pure and technical iron during deformation under cyclic changes of temperature M. G. Lozinskii, I. S. Simeonova, and A. E. Fedorovskii (*Izvest. AN SSR, OTN, Metallurg. i. Topl.*, 1959, (6), 24–36) The study of the experimental findings shows that an increase in the content of admixtures in the iron affects its strength in cyclic temp. changes. The value of the tensile strength of technical iron was found to be greater than that for pure iron by a factor of 11, and the deformation under the effect of the same number of cycles greater by a factor of about 3. Furthermore, the changes in the chemical composition due to the admixtures, lowers the temp. corresponding to minimum strength, which in these experiments corresponded to 750 ÷850°C.

The effect of shot-peening and if grinding on the fatigue strength of chromium plated high strength steel C. Williams and R. A. F. Hammond (*Proc. Amer. Electropl. Soc.*, 1959, 195–204) Rotating beam fatigue tests on heat-treated En25 and SAE 4340 steels showed that shot peening and surface rolling before plating greatly reduces the loss in fatigue strength caused by Cr plating. The fatigue strength may be maintained by shot peening before plating. The surface roughening resulting from peening can be removed by grinding either before or after plating without loss of fatigue strength.

Build stamina into metals (*Machine Design*, 1960, **32,** March 17, 28, 30) A general account of recent work on fatigue, residual stresses, and high strength alloys by the NBS is given.

The effect of creep at high temperatures on internal friction and modulus of elasticity I. A. Oding, M. G. Lozinskii, and L. K. Gordienko (*Metalloved. Term. Obra. Met.*, 1959, (12), 24–31) The change in the internal friction of technical iron and Ni–Cr alloys in the different stages of creep is characterized by the following pattern: (a) during the creep at a decreasing rate, the level of internal friction falls steadily; (b) during creep at an approximately constant rate the level of internal friction remains constant, and (c) during creep at an increasing rate the internal friction increases. Changes in internal friction and modulus of elasticity for the Ni–Cr alloy in stages I and III are the reverse of those for technical iron.

Interaction between creep and stress relaxation I. A. Oding and G. F. Lepin (*Metalloved. Term. Obra. Met.*, 1959, (9), 2–8) A theoretical consideration of the problem and derivation of certain equations which have been experimentally confirmed. They show that creep (under small loads) and relaxation are results of the same processes and that the different intensities of these processes condition the different character of the changes in stress with time. With large loads the process of failure becomes the influence determining the shape of the creep curve.

The effect of heat treatment on the heat resistance of 12KhMF boiler steel I. N. Bogachev and Kh. D. Reshetnyak (*Metalloved. Term. Obra. Met.*, 1959, (9), 8–12) Specimens of this steel were subjected to different alternative schedules of anneal and normalization and then tested for creep under bending on a specially adapted apparatus. The tests were carried out at 520 and 560° and lasted 400–500 h. Results are tabulated.

Investigating creep in iron at high temperatures under torsion L. N. Bystrov, L. I. Ivanov, and D. A. Prokoshkin (*Izvest. AN, SSSR, OTN, Metallurg. i Topl.*, 1959, (6), 37–42) The result of the investigation shows that the activation energy of creep under torsion between 1100 and 1180° does not change and equals 95·2 kcal/g atm. The absolute value of creep corresponds to the heat of vaporization of iron. According to its origin, this value is determined in all probability by two processes; self-diffusion and the regeneration of excess vacancies during deformation. This is confirmed also by the formation of cracks and pores in the body of the specimen.

The change in the mechanical properties and microstructure of metals during creep L. K. Gordienko and I. A. Oding (*Izvest. AN, SSSR, OTN, Metallurg. i Topl.*, 1959, (6), 52–65) The specimens examined consisted of technical iron and a Ni–Cr alloy. The basic assumption of the structure theory of creep as regards changes in the density of the dislocations at the different stages of creep has been confirmed experimentally. The effect on yield point characteristics of the increasing intergranular plasticity was established for the creep before it attains the constant rate.

Study on type 321 stainless steel intended for high-temperature service such as for superheater and reheater tubes. I. Study on influence of heat treatment and ferrite upon creep rupture strength of type 321 stainless steel M. Nishihara, H. Hirano, S. Yamamoto, and K. Yoshida (*Tetsu to Hagane*, 1959, **45,** Dec., 1357–1362) Good creep-rupture strength was induced by complete solution of TiC into austenite at high temp.; hence a quenching temp. above 1100°C is recommended. Specimens containing much ferrite in austenite had lower creep-rupture strengths than those having only a single austenite phase.—K.E.J.

Operational failure of welded structures under stress (*Riv. Ital. Saldatura*, 1959, **11,** (6), 248–263) The causes are analysed of many cases of weld failure.

An analysis of recent screwshaft casualties H. N. Pemberton and G. P. Smedley (*NE Coast Inst. Eng. Shipb., preprint*, 1960, March 14, 285–304) The causes of replacements in service are considered. No special increase in the rate is indicated.

The causes and prevention of spring failures E. Bruder (*Eng. Dig.*, 1960, **21,** April, 91–94; from *Der Maschinenschaden*, 1960, **33,** Feb., 13–18) Helical and leaf-spring failures are illustrated and discussed.

Test blocks for indentation hardness testing J. G. Wood (*Machine Shop Mag.*, 1959, **20,** Dec., 709–714) An account of NPL methods for the range 200–950 HV.

Microhardness testing and its uses H. Bückle (*Publ. Sci. Techn. Ministère de l'Air*, 1960, **NT,** 90, pp.274) Definitions, apparatus, measurement techniques, specimen preparation, impression measurements, various factors in the relation between hardness and diameter, and practical and research applications are discussed at length (176 refs).

Influence of ageing on the contraction work of steels G. Ziaja (*Per. Polytechn.*, 1959, **3** (2), 147–156) [In German] Experiments on three types of steel showed little or no influence of ageing on the results. Contraction work in cold working produced by uniaxial tension showed a marked reduction.

Relationship between internal stresses dimensional changes and structure in the hot bath hardening of steel H. Borchers and A. Safferling (*Arch. Eisenh.*, 1960, **31,** May, 291–297) Tests were made on two roller-bearing steels, and austenitic (20/12) steel and an Armco iron, by quenching in a salt-bath at 165°C. The effect of a subsequent tempering treatment on residual stresses was also examined. The specimens, in the form of plates, were quenched on two sides, small bars cut parallel to the quenched surfaces, and internal stresses measured by the elastic recovery. Specimens hardened throughout showed small tensile stresses in the surface zones and small compressive stresses in the core, and increase slightly in length. Specimens not hardened throughout are shortened in length, and have high compressive stresses near the surface and high tensile stresses at the core. Intermediate cases were found.

Electrochemical investigation for the determination of the activity of silica and alumina in the system calcium oxide–silica–alumina M. G. Frohberg and T. El Gammal (*Stahl Eisen*, 1960, **80,** July 21, 1025–1029) This is a review of recent publications by various authors, their results are summarized and presented in ternary diagrams. T.G.

Contribution to the study of the Portevin–Le Chatelier phenomenon J. Caisso (*Publ. Sci. Tech. Min. l'Air*, 1960, (357), pp.70) This phenomenon, of discontinuous extension during the plastic range of tensile tests, is examined for three Al–Mg alloys, a very pure iron and an 18–8 stainless steel. In the case of iron it is connected with structural hardening due to C and N and, after ageing is less noticeable in tests at 300°C than at lower temp.; in the 18–8 steel there is no structural ageing, and the phenomenon appears only between 500°C and 700°C. A tentative explanation, taking into account the effect of diffusion of impuriteis, and of dislocations on the freedom of propagation of stress waves is given.—J.P.S.

Mechanical properties of 17-7 PH and PH 15-7 stainless steel A. W. Brisbane (*WADC Techn. Rep.*, 58-400; *AD* 208322; *PB* 151703, 1959, Jan., pp.38; from *US Govt. Res. Rep.*, 1959, **32,** Nov. 13, 619) Tensile, compression, and bearing data were obtained and tensile–stress–strain test results are presented for temp. from room temp. to 1000°F. A comparison is made between these two steels and Am-350 stainless steel 6Al–4V–Ti strength–weight ratio wise. Strength-wise, the 17–7 PH and PH 15–7 Mo stainless steels are approximately the same to 800°F; above this temp. PH 15–7 Mo is superior.—S.H.-S.

The effect of temperature and deformation rate on the mechanical properties of carbon steels V. S. Zoteev (*Stal'*, 1960, (6), 552–555) Armco iron, St3, 45, and U10 steels were examined at 20–1200°C and increased rate of deformation showed increased yield point. Sensitivity to rate fell with increasing C content. An expression relating strength to deformation rate is given.

Statistical analysis of yield strength of HY-80 steel A. Lieberman (*PB* 139511, 1956, July, pp.13; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 367) No significant difference was found between compression and tension with respect to yield strength.

Application of induction heating to short-time elevated temperature tensile testing A. P. Levitt and A. G. Martin (*WAL TR* 116/1; *AD* 215626; *PB* 151848, 1959, June, pp.18; from *US Govt. Res. Rep.*, 1959, **32,** Sept. 11, 367) Tensile test results and limitations and possibilities of the technique are discussed, with reference to tests on plain and welded Ti alloys.

Relations between the notch tensile strength of cylindrical and prismatic specimens of titanium alloys and heat-treated steels G. Sachs, J. G. Sessler, R. F. Pray, and T. H. Yeh (*Trans. ASME J. Basic Eng.*, 1960, **82,** June, 401–410) The basic relations governing the behaviour of Ti alloys in the presence of stress concentrations as caused by notching were investigated for cylindrical and prismatic tension test specimens. Notch tensile strengths were determined at room temp. for 4340 steel heat-treated to various strength levels and for the Ti alloys 6 Al–4 V and 5 Al–1·5 Fe–1·4 Cr–1·2 Mo (Ti–155A). On the basis of these studies recommendations are made regarding the design of notch tensile specimens for evaluating the relative notch sensitivity of sheet alloys.

A method for determining the tensile properties of metals at high rate of strain A. L. Austin and R. F. Steidel jun. (*Proc. Soc. Exper. Stress Anal.*, 1959, **17,** (1), 99–114) An explosive impact tensile tester has been designed with provisions for direct and accurate measurements of load, impact velocity, and instantaneous changes of dia. as a function of time. A charge of gunpowder was used to propel a projectile threaded to one end of a specimen, the other end being fixed. Data obtained for steel and Al alloy verify the experimental apparatus and method. Dynamic stress–strain curves for these materials ineicated that strength increases with strain rate at room temp. The tensile properties of these materials have been obtained for strain rates as high as 17000/in./sec. by this method.

Study of the elastic limit discontinuity of high-purity iron, and a contribution to the study of precipitation phenomena by measuring the electrical resistivity at low temperatures B. Migaud (*Rev. Mét. Mem. Sci.*, 1960, **57,** Feb., 125–152) In tests on zone-melted and electrolytic Fe it is shown that an upper and lower elastic limit is found only if the specimen is quenched from 720°C followed by ageing. It is considered that C contents of 8–10 ppm can be held in solid solution. The fact that the purity of the iron plays an important part in determining the discontinuity is discussed. The kinetics of C precipitation are examined by adding varying amounts of C to pure Fe. Several stages in precipitation have been established, according to ageing temp.; at low temp. the precipitates are detected by mechanical properties and electrical resistivity (17 refs).

Investigation of effects of stress concentrations and cracking tendency of heat treated titanium and steel sheet alloys J. G. Sessler (*PB* 137494, 1958, Oct., pp.11; from *US Govt. Res. Rep.*, 1959, **32,** Oct. 16, 500) Room temp. tensile tests were performed on notched and smooth specimens taken from annealed Ti–6Al–4V sheet, aged Ti–6Al–4V and aged Ti–16V–2·5Al.—S.H.-S.

Now you can determine minimum bend radii from standard tensile test results J. Datsko and C. T. Yang (*Mat. Des. Eng.*, 1960, **51,** May, 128–129) Formulae are computed for sheet materials and a curve apparently valid for all materials and derived from cast iron, carbon, and tool steels and non-ferrous metals is given. The method of calculation is shown.

Yield stress of austenitic stainless steel for pressure vessels in the temperature range 20–500°C, and proposal for new calculating values for these steels B. Hermelin (*Jernkont. Ann.*, 1960, **144,** (1), 77–101) Values for yield strength specified in the Swedish Code for Pressure Vessels, 1949, are discussed and modifications suggested.

Non-metallic inclusions and fracture behaviour of steels S. Yukawa (*Trans. ASME, J. Basic Eng.*, 1960, **82,** June, 411–416) This article concerns the adverse effects in tests at low and high temp. and under steady and cyclic loading of certain kinds of non-metallic inclusions on the strength and fracture behaviour of alloy steel test specimens. Definitive results are however difficult to obtain.

Precipitation hardening of copper in low-carbon steels Z. Csepiga (*Koh. Lapok*, 1959, **14,** Nov., 506–514) The precipitation-hardening effect of up to 0·92%Cu on low-carbon steels has been mathematically and graphically determined by means of tensile and impact tests and magnetic measurements.—P.K.

Calculating the mechanical properties of wire (discussion) D. Mankkher and L. Mankkher (*Stal'*, 1960, (6), 569–571) The equations of K. I. Tulenkov, M. I. Zlotnikov, and S. F. Bobyleva is compared with values observed at a works over a long period. Causes of deviations are discussed.

Static bend tests of tool steels F. Joanxich Ayma (*Inst. Hierro Acero*, 1960, **8,** Jan., Special Number, 76–87) Bend tests have been used in conjunction with hardness measurement and metallographic examination to determine the properties of five Cr–V type tool steels with respect to service conditions. Isothermally treated specimens were also examined and compared. The optimum condition for each type of steel is given.—P.S.

A study of the quench-ageing and strain-ageing embrittlement in steels National Metallurgical Laboratory, Jamshedpur (*Nat. Met. Lab. Ann, Rep.*, 1958–59, 9) A table showing the compositions of steels prepared in high-frequency furnaces is given together with a brief note on the tests carried out.

Some observations on the brittle fracture problem G. M. Boyd (*Welding Research Council Bulletin Series*, No.57, 1960, Jan., pp.9) The shear and cleavage modes of fracture are described and illustrated, and the fundamental considerations governing the stability or instability of fractures are discussed. The choice of a test, and suitable criteria, in order to be able to predict the behaviour of a given specimen is also considered, and it is felt that the Charpy V notch impact test is the most suitable available at present.

Research on the mechanism of brittle fracture. Progress report P. R. Lagasse (*Soud. Techn. Connexes*, 1959, **13,** Sept.–Oct., 391–397) A review of the literature published in 1957–1958 (77 refs).

Contribution to the study of the mechanism of brittle fracture in mild steel J. B. Lean, J. Plateau, and C. Crussard (*Rev. Mét. Mém. Sci.*, 1959, **56,** Sept., 427–452) Mechanical properties and brittle fracture in mild steel were examined on polished and notched specimens, and apparent activation energies were determined in relation to mechanical properties and brittle fracture. It is concluded that even under severe testing conditions, brittle fracture would occur in areas of abnormal distribution of properties which were examined, when a certain critical deformation was exceeded.

The effect of a fine-grained surface layer of the cold-shortness of steel P. S. Sakharov (*Metalloved. Term. Obra. Met.*, 1959, (9), 55–57) It was established experimentally that a fine-grained surface layer may reduce the tendency to cold shortness. The best method of producing such a layer is by induction heating above the Ac_3 point with subsequent cooling in air, i.e. high-frequency normalization. The recrystallization proceeds under these conditions very rapidly and produces only ferrite and pearlite grains.

The irreversible temper-brittleness of structural steels V. I. Sarrak and R. I. Entin (*Izvest. AN, SSSR, OTN, Metallurg. i Topl.*, 1959, (6), 73–83) The irreversible temper shortness is the result of martensite decay and can therefore hardly be eliminated completely. The present experiments have however resulted in effective suggestions for reducing its incidence. This may be attained, *inter alia*, by lowering the threshold of cold shortness with low heat tempering of the steel (by the refinement of grains, reduction of impurities and gases, increasing hardenability) and by displacing the appearance of temper-brittleness towards higher temp. by suitable alloys which delay the decay of martensite.

Relation between the appearance of brittle fracture in ductile metals and their stress condition G. V. Oujik (*Rev. Mét. Mém. Sci.*, 1959, **56,** Oct., 505–511) The mechanism of crack formation at a sharp and deep notch is discussed and related to the tendency of ductile metals to produce a fully brittle fracture.

The causes of hydrogen brittleness of steels after pickling P. G. Kovtun (*Metalloved. Term. Obra. Met.*, 1959, (9), 58–59) It has been established that the reduction of plasticity with pickling occurs in these steels in the structure of which the crystalline texture was not destroyed after heat treatment. It has not proved possible to reveal metallographically the presence of a texture.

The effect of alloying low carbon steel with chromium and manganese on its tendency to brittle fracture V. G. Savitskii, K. V. Popov, V. F. Sakharov, and G. M. Grigor'eva *Metalloved. Term. Obra. Met.*, 1959, (9), 49–51) Independent of the rate of deformation, the coarsening at low temp. of the steels investigated is occasioned by the disappearance of the property of the metal of plastic deformation; under impact deformation at very low temp. the strength is sharply reduced. A smaller degree of cold brittleness in low alloy steels in comparison with carbon steels occurs only in heat-treated steels. It follows that low-alloy steels should be used for components serving at very low temp. only if previously heat treated.

The effect of heating welded joints at high temperatures in a hydrogen atmosphere on their brittleness L. S. Livshits, L. P. Bakhrakh, I. D. Grebeshkova, and V. P. Teodorovich (*Metalloved. Term. Obra. Met.*, 1959, (9), 52–55) The presence in the welded joints of Cr–Mo–W–V with increased Mn (>0·4%) and Cr (>3·0%) contents results, with prolonged heating in H_2 at high pressures, in hot-shortness and additional coarsening of the grain. The addition of elements forming stable carbides does not prevent the damaging influence of H_2 on the plasticity of the metal.

Detection of phenomena of intergranular adsorption and examination of their relation to intergranular brittleness G. Henry, J. Plateau, X. Waché, M. Gerber, I. Behar, and C. Crussard (*Rev. Mét. Mém. Sci.*, 1959, **56,** Sept., 417–426) Micro-geometric changes in the shape of the grain boundaries of commercial Ni subject to intergranular brittleness are analogous in several respects to those occurring at

the commencement of oxidation at metal surfaces, and can be explained by adsorption at the grain boundaries of atoms in solution in the lattice.

Hydrogen embrittlement of high-strength steels during cadmium, chromium and electroless nickel plating W. L. Cotton (*Plating*, 1960, **47,** Feb., 169–175) Tests on five representative aircraft steels heat-treated to various tensile strengths up to 300000 psi, by static loading plated specimens to a minimum of 75% of the notched UTS, and determining the time to failure, are described and evaluated.—S.H.-S.

The brittleness of chromium–manganese–nickel steel and its reduction by means of additional alloying M. P. Braun (*Izvest. VUZ Chern. Met.*, 1959, (10), 99–107) The plasticity of this steel was investigated when alloyed with Ni, W, Mo, Ti, and Al. The tendency to temper brittleness is reduced by 0·17%Ni, 0·6–0·7%W, and 0·3%Mo but the greatest effect is shown by complex alloying with W+Ti or W+V.

A replication technique for the study of brittle fracture of ship plate steel by electron microscopy E. C. Haas (*Ship Structure Committee*, SSC–119, 1960, Jan., pp.14) A five-step replica procedure is described and study of steels of different transition temperatures showed a correlation with the degree of separation of the cementite lamellae, increase of ordering being associated with higher transition temp.

The cruciform test for plate-cracking susceptibility L. E. Poteat and W. L. Warner (*Weld. J.*, 1960, **39,** Feb., 70s–76s) An investigation of the test was made to determine the effect of different conditions on the ability of the test to separate a crack-susceptible heat of armour steel from a non-crack susceptible heat. Conditions investigated were specimen fit-up, specimen temp. (preheat and interpass), and specimen size. Results indicate that the test is more sensitive to testing conditions than it is to differences in degree of crack susceptibility of the base metal used.

Factors affecting severity of cruciform test for hardened-zone cracking K. Winterton and M. J. Nolan (*Weld. J.*, 1960, **39,** Feb., 77s–82s) The cruciform test and the controlled-thermal-severity test were compared using a particular combination of metal-arc electrode and alloy-steel plate, and it was shown that the cruciform test is a more severe hardened-zone cracking test than the C.T.S. test. The reasons for this greater severity were then investigated and the results obtained are presented.

Transience of the state of wear by repeated rubbing T. Sata (*Wear*, 1960, **3,** March–April, 104–113) In repeated frictional movement, where rate varies with the rubbing distance, being generally high at the beginning of the movement, falling with the moving distance, and finally reaching a constant value. The transition is discussed, and a special wear-testing machine is described.—S.H.-S.

The influence of work-hardening on the coefficient of friction C. Rubenstein (*Wear*, 1960, **3,** March–April, 150–153) In the case of soft metals, polymers, and lubricated hard metals, the degree of work-hardening of the material when sliding commences determines whether or not Amonton's laws of friction are obeyed. An attempt is made to show that Tabor's analysis leads to the same conclusions as those published by the author.—S.H.-S.

Stratimetry J. A. Ternisien (*Mét. Corros.-Ind.*, 1959, **34,** Dec., 485–492) A technical review of friction, comprising conditions of friction and wear of surfaces under micro-rheology of states of surfaces. Macrorheology of lubricant beads; friction of metallic surfaces at low speeds, and at high speeds. Coefficients of friction of metallic surfaces and hot friction are given as well as coefficients of friction for Mo. Modern high-speed examples are cited.

How to predict wear life of rolling surfaces D. J. Myatt (*Prod. Eng.*, 1960, **31,** May 9, 44–47) A table of load-stress K factors and equations for wear life of various types of components are given.

Erosion of surfaces by solid particles I. Finnie (*Wear*, 1960, **3,** March–April, 87–103) Aspects of fluid flow conditions which may lead to erosion are discussed and the mechanisms of removal of ductile and brittle material are analysed.—S.H.-S.

Friction and 'sulfinuz' Y. de Villemeur (*Mét. Corros. Ind.*, 1959, **34,** Nov., 413–446) A review on friction in general, supported by a number of tests and rules for the choice of materials and their treatment in mechanical uses. The measurement of friction, dry, wet, and with oil, by the Favilla–Levally machine is described in detail.—S.H.-S.

The erosion of the 40 Kh, 40 KhN and 30 GL steels as related to heat treatment V. M. Shengalev and K. A. Kochuev (*Metalloved. Term. Obra. Met.*, 1959, (11), 49) The erosion of these steels depends on their hardness. A linear relation exists between the absolute loss in weight by erosion and the corresponding hardness. For low hardness (150–200 H_B) the erosion of 30 HL and 40 KH steels is the same but for medium and high hardness, the erosion of 40 Kh steel is greater.

Strengthening pump piston rods operating under conditions of erosion fatigue R. M. Raskin and R. A. Bagramov (*Metalloved. Term. Obra. Met.*, 1959, (12), 35–38) It has been experimentally demonstrated that in erosion fatigue with asymmetric loads the effectiveness of surface hardening by high-frequency current is reduced by an increase in the average load of the cycle. The cause is obviously the internal tensile stress. The experimental diagram for limiting loads may be used for calculating the strength of piston rods.

Optical methods of studying surface finish O. S. Heavens (*Trans. Inst. Met. Fin.*, 1959, **36,** Autumn, 159–165; discussion 165–166) Straight microscopy, interference microscopy, light profile microscopy, multiple beam interferometry, and reflectivity measurement methods are described and compared.—A.D.H.

Some observations of phenomena related to penetrant detection of cracks P. S. Heneghan (*Nondestr. Test.*, 1960, **18,** March–April, 121–123) Experiments and observations on the use of alcohol penetrant oil and its movement in cracks as a means of understanding how the process works are described with the conclusion that the three-dimensional aspect of penetrant oil movement in cracks allows for much greater flow than was visualized in previous approaches.—S.H.-S.

Origin of the magnetic anisotropy of compounds M. Tachiki (*Met. Phys.*, 1959, **5,** July, 147–155) A review (26 refs).

Studies of the magnetic anisotropy induced by cold rolling of ferromagnetic crystal. II. Iron-aluminium alloys S. Chikazumi, K. Suzuki, and H. Iwata (*J. Phys. Soc. Japan*, 1960, **15,** Feb., 250–260) [In English].

Time decrease of permeability in silicon iron K. Tsushima, M. Asanuma, and S. Miyahara (*J. Phys. Soc. Japan*, 1959, **14,** Sept., 1253) This note describes certain experiments on 4%Si–Fe. Specimens were annealed in purified H_2 at 850°C for a week to remove as much C and N_2 as possible. Initial permeability was measured on a toroid. Time decrease at each temp. is shown on a graph. Up to $g=0{\cdot}3$ a straight line relationship is found and the slopes give the value of activation energy $\phi = 0{\cdot}80 \pm 0{\cdot}04$ ev.

Methods for the experimental investigation of domain structure B. Wyslocki and M. Markuszewicz (*Prace Inst. Hutn.*, 1960, **12,** (1), 21–37) The authors discuss the experimental and theoretical results of the more important work done on domain structure. The experimental method depends on the observation of 'powder patterns' formed from a colloidal suspension of ferro-magnetic Fe_3O_4, applied to the crystal to be examined. The domain structure is influenced by the orientation of crystals, impurities, residual stresses, and external magnetic fields.

Magnetic susceptibilities of iron–chromium alloys M. M. Newmann and K. W. H. Stevens (*Proc. Phys. Soc.*, 1959, **74,** Sept., 290–296) High-Cr alloys were used.

Magnetic and electric anomalies of iron telluride single crystals R. Naya, M. Murakami, and E. Hirahara (*J. Phys. Soc. Japan*, 1960, **15,** Feb., 360–361) [In English].

Magnetic properties of iron phosphide Fe_2P S. Chiba (*J. Phys. Soc. Japan*, 1960, **15,** April, 581–585) With a new device for the measurement of magnetization it was found that the extrapolate saturation of magnetization at absolute zero temp. reaches 66·3 Gauss/g iron corresponding to a spin moment of $0{\cdot}85 \pm 0{\cdot}02$ Bohr magneton per iron atom. The ferromagnetic Curie point is at 306°K. The Curie–Weiss law holds up to 900°K with the paramagnetic Curie point 478°K and the effective magneton number is $3{\cdot}2 \pm 0{\cdot}2$.

On the magnetic susceptibility of FeF_2 A. Honma (*J. Phys. Soc. Japan*, 1960, **15,** March, 456–463) [In English].

Magnetic anisotropy and magnetostriction of ordered and disordered cobalt–iron alloys R. C. Hall (*Trans. Met. Soc. AIME*, 1960, **218,** April, 268–269) The magnetic anisotropy and magnetostriction of single crystals of alloys between 25 and 59 wt·%Co in Fe have been determined in the disordered and ordered states. The magnetostriction is large and positive for all alloys in both states of order (up to 150×10^{-6} for γ_{100} and 40×10^{-6} for γ_{111}). The magnetic anisotropy becomes zero near 41%Co for the disordered state. Ordering shifts the zero-anisotropy composition to about 50%Co.

Magnetic properties of nickel and cobalt ferrite–chromite series S. Miyahara and T. Tsushima (*Met. Phys.*, 1959, **5,** July, 156).

Measurement of the permeability tensor of ferrites at 3000 and 8500 megacycles per second F. Dachert and A. Schmouchkovitch (*J. Phys. Radium*, 1960, **21,** March (Supplement to No.3) 57A–64A).

Electrical and magnetic properties of some low-manganese, low-aluminium steels (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 21) Work aiming at the development of low-Mn, low-Al steels to replace the conventional 4%Si steel sheets is described. The magnetic properties of two analyses, 4%Al, 2·5%Mn, and balance iron and 3%Al, 4%Mn, and balance iron, deoxidized with calcium were found to be encouraging.

The thermal and electrical conductivities of ductile cast iron and several grey cast irons J. M. Brophy and M. J. Sinnott (*BCIRA J. Res. Dev.*, 1960, **8,** March, 266–272; *Trans. ASM*, 1959, **51,** preprint No.139) This note describes the results of an investigation into the effect of graphite size, shape, and distribution on the thermal and electrical conductivities of cast irons. The conclusion is that owing to the non-metallic behaviour of graphite a simple correlation between the electrical and thermal conductivities of flake and nodular graphite cast irons in the form of the Wiedeman–Franz Ratio or Lorentz Number is not possible.

Aluminium alters density of electrical steel R. J. Bendure (*Met. Prog.*, 1959, **76,** Nov., 117–119) The following formula to take into account the effect of Al is suggested to replace the standard ASTM formula: Density (g/ml) = 7·85–0·059%Si–0·113%Al or as an approximation: Density = 7·85–0·059[%Si + (Al.2)].

Electrical conductivity of α-Fe_2O_3 T. Nakau (*J. Phys. Soc. Japan*, 1960, April, 727) This note describes a measurement of electrical conductivity carried out on natural crystal samples of α-Fe_2O_3 containing impurities such as Ca, Mg, and Sn. A certain anisotropy was revealed in both the value of conductivity and the slope of the curve of log conductivity versus reciprocal temp. and also an anomaly near the transition temp.

Autodiffusion of iron in bulk and at grain joints C. Leymonie (*Met. Corros. Ind.*, 1959, **34,** Dec., 457–474) A review of the characteristics of intergranular autodiffusion: (1) iron; (2) the problem of intergranular diffusion of iron, with characteristics of radioisotopes; (3) experimental methods, electrolysis, preparation of samples of iron; (4) observation of intergranular diffusion; (5) importance of the phenomenon; (6) intergranular autodiffusion of iron and structure of joints of grains; (7) influence of parameters defining geometrically the joints of grains in autodiffusion; (8) application of autoradiographs obtained after diffusion; (9) direct evidence of diffusion in the sub-points of polygonization; (10) intergranular diffusion of radioactive iron in Ni.—S.H.-S.

Surface reactions and diffusion in plates G. Scheeweiss (*Osterr. Ing. Zeits.*, 1959, **2,** Oct., 376–386) A mathematical treatment. Changes

in concentration due to surface reactions and diffusion are calculated by solving Fick's diffusion equation with the corresponding spatial (surface reaction) and time-dependent (initial concentration) boundary conditions. The equations derived are checked against experimental determinations of C and N diffusion in steel, and the diffusion of H in Pd (21 refs).

Kinetics of absorption by metals of hydrogen from water and aqueous solutions T. G. O. Berg (*Corrosion*, 1960, **16,** April, 198t–200t) The author discusses the kinetics of absorption of H_2 in corrosion on the basis of a mechanism previously proposed for the absorption of H_2 from H_2 gas. Rate formulae are derived and compared with experimental data.—G.F.

Penetration into iron of the cathodic hydrogen evolved from neutral and alkaline solutions H. Angerstein-Kozlowska (*Bull. Acad. Polonaise Sci.*, 1960, **8,** (2), 49–52) [In English] Torsion and embrittlement tests on wires were made and show that results in alkaline and neutral solution can be made identical with those in acid conditions by adding a promoter. Cathodic AsH_3 appears to be the actual promoter in the presence of As compounds.

Method of measuring the surface tension of iron K. I. Vashchenko and A. P. Rudoi (*Izvest. VUZ Chern. Met.*, 1959, (9), 133–139) An improved arrangement for measuring the surface tension of molten metals is described with small-inertia microgauges and small measuring volumes which make it possible to determine accurately the pressure in blisters or alternatively small tubes of alumina or BeO as well as of quartz which all have a high resistance to heat.

Interphase tension in low carbon steel at the interface with the deoxidation products S. I. Popel' and G. F. Konovalov (*Izvest. VUZ Chern. Met.*, 1959, (8), 3–7) It has been experimentally established that MnO has a slightly smaller surface activity than FeO at the interface of low carbon steel with fused silicates. The capillary activity of MnO is due to the weakening of the bonds between the particles in the iron with the dissolved MnO and its replacement by FeO in the surface layer. The reduction of the interfacial tension of alloys enriched in FeO and MnO at the boundaries with the iron, and the increase in their adhesion to the metal also increases the strength of the emulsion to these oxides in the steel.

Influence of cold work on hydrogen behaviour in steel R. M. Hudson, K. J. Riedy, and G. L. Stragand (*Corrosion*, 1960, **16,** March, 115t–118t) The authors present data showing that cold work markedly affects the solubility and adsorption and desorption rates of H_2 in steel. The effect of processing variables on H_2 behaviour in steel is also discussed.—G.F.

Rate of pickup and solubility of nitrogen in liquid iron as a function of dissolved oxygen W. A. Fischer and A. Hoffmann (*Arch. Eisenhüt.*, 1960, **31,** April, 215–219) N_2-pickup and saturation solubility were investigated at 1600°C, under N_2-partial pressures of 50–500 mm Hg, in steels containing 0·001–0·020, and 0·15–0·24%O. N_2 increases steeply with rising O-content, and a quantitative relationship is derived. The saturation solubility of N_2 in iron is determined, and is independent of O-concentration (23 refs).

Add columbium to killed steel to retard grain growth E. E. Fletcher and A. R. Elsen (*Iron Age*, 1960, **185,** Feb. 25, 72–73) Results of tests on the effect of Nb on Al-killed steel are presented. Additions of 0·012, 0·09, 0·17, 0·35% Nb were made to heats of the steel. Increasing proportions progressively inhibited grain growth. The smallest addition had the most effect on yield strength which was increased without loss of ductility.—D.L.C.P.

Molybdenum I. S. Plumtree (*Machine Shop Mag.*, 1959, **20,** Oct., 584–586) A review with a large section on steel where the effects of Mo are given in general terms.

Columbium added to steel makes pipe more weldable Great Lakes Steel Corp. (*Steel*, 1960, **146,** April 11, 102) Properties and uses of fine-grained, semi-killed mild carbon steel, treated in the OH with 0·01–0·04%Nb are described. Nb increases tensile properties without affecting ductility, weldability is improved, and welding can be effected at sub-zero temp. without special precautions. The properties have been found valuable for gas pipelines.

The hardening and softening of ferrite alloyed with manganese L. I. Mirkin (*Izvest. VUZ Chern. Met.*, 1959, (6), 63–66) Alloying iron with Mn in the proportions of 1·5 and 3% results in an increase in the strength characteristics; these increase with an increase in the alloy element. The softening of the alloy in heating is delayed by 150° by 1·5% and by 250° for the 3%Mn addition. The increase in internal friction begins at higher temp. with the 1·5% proportion and the shear modulus is also higher at all temp.

The hardening and softening of ferrite alloyed with vanadium L. I. Mirkin (*Metalloved. Term. Obra. Met.*, 1959, (9), 39–41) The changes in the mechanical properties and the metallographic structure of these alloys was investigated. For the purpose, carbon-free ferrite specimens alloyed with V and work-hardened were used. They were kept at high temp. at a pressure of 10^{-4} mm. Measurements of mechanical properties and internal stresses have shown that V reduces the strength characteristics in deformation, does not increase hardness in annealed specimens and reduces the shear modulus.

Zone levelling of boron into zone-melted iron B. F. Oliver and A. J. Shafer (*Trans. Met. Soc. AIME*, 1960, **218,** April, 194–195) Pure boron was successfully single-pass zone levelled into zone-melted iron in a floating-zone apparatus. A zone-stabilizing direct current of 120 amp. was passed through the bar during zone levelling. The effective redistribution coefficient for boron in iron is 0·16 ± 0·03.

Hafnium as alloying element for copper, iron, and nickel R. Reinbach (*Z. Metallk.*, 1960, **51,** May, 292–294) Hf as an alloying element for Cu, Fe, and Ni effects property changes in these base metals which resemble in many respects those imposed by Zr and Ti. Particularly marked is the increase in electrical resistance and in recrystallization temp. The solubility limit of Hf in Fe is about 0·2 wt·%.

Quality requirements of super-duty steels J. F. Elliott (*AIMME Proc. OH Comm.*, 1959, **42,** 120–125) The author reviews a number of papers on the above subject presented at an AIMME technical meeting, drawing particular attention to facts and viewpoints pertinent to carbon steel production in OH furnaces.—G.F.

Studies on austenitic heat-resisting steel Y. Konishi, T. Akutagawa, T. Fujita, R. Nakagawa, and Y. Otoguro (*Trans. Nat. Res. Inst. Met.*, 1959, **1,** (2), 100–106) Using Haynes Stellite 88, the effects of addition of Co and Nb on age-hardness and creep strength and the effects of Al and increased Ni and Co were examined.

The steel for components of large cross-section M. P. Braun, B. B. Vinokur, A. I. Kondrashev, and B. E. Maistrenko (*Izvest. VUZ Chern. Met.*, 1959, (6), 67–73) The investigation of steels of different composition has shown that Cr–Mn–Ni–W and Cr–W steels possess satisfactory strength, plasticity, and ductile properties but have to a small degree a tendency to temper brittleness. The investigation of the mechanical properties of forgings of various cross-sections and in various directions have confirmed the conclusions that 35 KhGNV steel and 35 KhNM steel are qualitatively equivalent.

Steels for surface hardening K. Z. Shepelyakovskii (*Metalloved. Term. Obra. Met.*, 1959, (11), 24–39) There are considerable technological and economic advantages connected with high-frequency surface hardening but it can only be applied to steels with a certain range of chemical composition and mechanical properties suitable to withstand rapid induction heating. Steels for this purpose have to be evolved.

High speed steels of increased efficiency (Supplement to *Metalloved. Term. Obra. Met.*, 1959, (11), 31–34) Specifications are listed for the following types of steel: R 18 F 2 M (EI 917); R 14 F 4 (EI 915); R 9 F 5 (EI 706); R 9 K 10 (EI 919); R 18 K 5 F 2 (EI 940); R 10 K 5 F 5 (EI 931).

New air hardening steel can improve wear resistance Braeburn Alloy Steel Corp. (*Steel*, 1960, **146,** March 28, 84–85) The composition and properties of a newly-developed steel called 'Airque V' are described. Typical analysis is: 1·25%C, 0·5%Mn, 0·3%Si, 5·25%Cr, 1·15%Mo, 1·0%V. The combined qualities of shock and wear resistance make it suitable for gauges, slitters, knives, and dies. The optimum hardening temp. is 1800°F, and the ability to harden in air keeps distortion to a minimum.

Jessop-Saville R 22 steel (*Data sheet*, 1959, Sept., M29/6, pp.6) Physical properties of the steel with 11·5%Ni, 22·5%Cr, and 2·7%W are given.

Can AISI 4140 steel replace special nitriding grades? W. Simon (*Iron Age*, 1960, **185,** Feb. 4, 92–94) Work is described which shows that low-alloy steels (not special nitriding steels) can be nitride-hardened sufficiently for many applications. Contrary to earlier reports, the core hardness before treatment is not critical. A special single cycle process is preferable to the standard two-cycle process.—D.L.C.P.

High-temperature rolling and forging steels (*Stahl-Eisen, Werkstoffblatt*, 470–60, fourth edn. March 1960, pp.6) The steels dealt with in this specification are all produced in the electric arc furnace, the steels should be scale-resistant at temperatures above 600°C. In tables are listed: composition, mechanical and physical properties, scale-resistance and high-temperature applications, hot-working, and welding properties.—T.G.

Stainless rolling and forging steels (*Stahl-Eisen Werkstoffblatt*, 400–60, 3rd edn. March 1960, pp.11) This specification contains data on steels containing at least 12%Cr. All steels are produced in the arc furnace. Working, heat-treatment, and testing of the steels are dealt with. Tables give the composition mechanical and physical properties, application, hot working, and welding of the steels.

A boron stainless steel with better toughness, corrosion resistance (*Mat. Design. Eng.*, 1960, **51,** April, 9–10) This brief note describes a new 304-base stainless steel containing up to 2%^{10}B for use in nuclear plant which has a high neutron absorption and excellent mechanical properties. Details of its production and processing are given.

Development of low-alloy high-tensile structural steels (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 26) Development has concentrated on steels with ferrite–pearlite structures. Experimental heats were made using Mn, Si, Cr, Cu, P, Al, Ti, B, etc. as alloying elements. The Mn–Cr class with addition of Cu showed unusually high strength combined with fair elongation values. In impact testing, certain of the low-alloy steels showed high impact figures even at lower temp.

Nickel-free, austenitic chromium nitrogen–manganese–copper stainless steels (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 5–6) Comprehensive investigations on the determination of mechanical and corrosion resistance properties of austenitic nickel-free stainless steels in various media are described. The results showed that with 25–30%Cr the steels were never fully austenitic irrespective of their Mn content of 5–35% and Ni content of 0·3–1·06%. At high Mn levels the steels became brittle. With 22%Cr and 10%Mn the steels again failed to become austenitic. In steels with 15%Cr, 10%Mn produced martensitic steels. On increasing to 14%Mn the steel became more stable but underwent phase transformation on cold working. The steels containing 10%Cr had very poor corrosion resistance.

Scope of pilot plant research and development at the National Metallurgical Laboratory B. R. Nijhawan (*NML Tech. J.*, 1960, **2,** Feb., 11–23) A survey of research and development work by NML in the Indian mineral and metal fields, with reference also to projected expansion in a further Five Year Plan.—S.H.-S.

The Golden Jubilee of the Institute for Ferrous Metallurgy at Rheinisch-Westfälische Technische Hochschule Aachen H. Schenck (*Stahl Eisen*, 1960, **80,** June 23, 849–853) A review.—T.G.

Finishing tests on coiled springs (*Ind. Fin.*, 1960, **12,** April, 46–49) A description is given of the recently opened laboratories of the Coil Spring Federation Research Organization in Sheffield. The equipment is described and a brief outline is given of the research projects undertaken.—G.F.

Pilot plants in metallurgical research and

development B. R. Nijhawan (*Iron Coal Trades Rev.*, 1960, **180**, May 13, 1065–1071) A report on an Indian symposium.

Iron, steel and ferroalloys investigated at Bruceton N. B. Melcher (*J. Met.*, 1960, **12**, May, 406–409) A review of the work and a description of the Bruceton Pyrometallurgical Laboratory at Bruceton, Pennsylvania.

METALLOGRAPHY

Methods used at the BCIRA Laboratories for the preparation of microspecimens R. W. Turner (*BCIRA J. Res. Dev.*, 1960, **8**, March, 238–246) The techniques in use at the Association's laboratories for the preparation of cast iron microspecimens are described. Simple and economical, they enable a good quality specimen to be prepared in about 5 min from receiving the ground sample.

Electrochemical techniques in modern metallography P. A. Jacquet (*Proc. Amer. Electropl. Soc.*, 1959, 240–254; discussion 383) Fundamentals of electrolytic polishing and etching and laboratory and industrial applications of the technique are reviewed (100 refs).—A. D. H.

Sodium bisulphite as an etchant for steel J. R. Vilella and W. F. Kindle (*Met. Prog.*, 1959, **76**, Dec., 99–100) $NaHSO_3$ in aqueous solution improves the contrast of the microconstituents of steel; martensite and pearlite are etched at the same rate, good contrast is provided between martensite and ferrite without excessive attack on the fine pearlite structure. Some photomicrographs are reproduced.

The demonstration of ferrite in unalloyed hypoeutectoid steels H. Klemm (*Neue Hütte*, 1960, **5**, May, 298–299) An illustrated account of etching methods.

Electrolytic potential in electrolytic isolation of cementites of ball bearing steels M. Ueno and H. Nakajima (*Trans. Nat. Res. Inst. Met.*, 1959, **1**, (2), 95–99) A study of the incomplete solution phenomena observed in electrolytic isolation was made relating the 'peeling' to composition and potential. Copper content was important as was austenitizing temp.

The effect of the mode of deoxidation on the nature of non-metallic inclusions and on the mechanical properties of the steel M. Mandl, J. Skala, and F. Poboril (*Hutn. Listy*, 1960, **15**, (2), 109–119) Samples of 0·23%C steel from the same heat were alloyed in separate small ingots with varying amounts of S and Al, the former being in the range 0·021–0·43%, and the Al additions 0–1·6 kg/t. Impact strength, fatigue limits, and other mechanical properties were determined on specimens swaged from the steel at 1000°C, and normalized for 1 h at 850°C, followed by air cooling. Al additions were found to reduce plasticity if more than 0·4 kg/t is used. The effect is due to intergranular segregation, and is enhanced with high S content. With adequate forging the impurity networks are broken down, and become ineffective in reducing notch impact values. With deoxidation utilizing complex Fe–Mn–Si–Al alloys the composition of the impurities and the total impurity content are influenced by the Mn:Si and Si:Al ratios, and also by the actual concentration of the individual elements. Analyses of the influence of the Al_2O_3 content of the inclusions on the magnitude of the equilibrium constant $K_{Mn\ Si}$ showed that with increasing alumina contents the values of the constant become smaller. Best mechanical properties result on using liquid Fe–Mn–Si–Al deoxidants. A relation between the total inclusion content and the mechanical properties, particularly the fatigue strength was established. In the final deoxidation with graded quantities of CaSi and Al, the best mechanical properties, high purity and best quality were obtained with weight ratios of CaSi:Al approximately 1:1.—P. F.

Structure of carbides in alloy steels (*Nat. Met. Lab. Ann. Rep.*, 1958–59, 22) Experiments are described which showed that carbides in 5%Cr and 0·8%C steel are of a Cr_7C_3 type. However X-rays showed that a steady displacement of iron atoms by Cr atoms occurred as the transformation period lengthened.

The character of the stratification of flakes in hypereutectic steels I. E. Brainin and S. I. Shapovalov (*Izvest. VUZ Chern. Met.*, 1959, (6), 81–82) Eutectic U8 steel and hypereutectic U12 steel were investigated and flakes were obtained by saturating the specimens with H_2 for 10 h at 1200° in a tubular furnace. The place where flakes are deposited is determined by the coarseness of the structural components. In hypoeutectic steels in which the grain boundaries consist of ductile ferrite, the flakes penetrate into the grains by the pearlite lattice while in the hypereutectic steels they propagate chiefly along the grain boundaries by the cementite lattice. An amount of H_2 sufficient to form flakes in hypereutectic steel proved insufficient for flake formation in eutectoid steels in spite of more rapid cooling after saturation with H_2. This is explained by the greater ductility of the eutectoid steels.

The mechanism of precipitation of special carbides, particularly vanadium carbide V. Foldyna and J. Wozniak (*Hutn. Listy*, 1960, **15**, (1), 33–40) A literature survey is made, and the author's own experiments on the precipitation of V_4C_3 are described. The mechanism of precipitation of vanadium carbide on tempering martensite is qualitatively similar to the process of precipitation as observed on tempering bainitic structures. In both cases the carbide is precipitated from the solid solution. The gradual dissolution of cementite is facilitated by the impoverishment of the solid solution of carbon, due to the precipitation of vanadium carbide. This upsets the equilibrium between the alloyed ferrite and the cementite. The carbon thus lost tends to be replaced by C from cementite. The time difference between the formation of vanadium carbide in tempering martensite and annealing bainitic structures is not due to a change in the mechanism of carbide precipitation. This is also true of the displacement of the maxima of secondary hardening. A detailed description of the work, which is particularly relevant in connexion with low-alloy steels of high creep strength, is given.

Carbide precipitation and evolution and depletion of matrix in heat resisting steels and alloys treated in carburizing atmospheres G. Pomey (*Trans. Met. Soc. AIME*, 1960, **218**, April, 310–314) Heat-resisting Cr steels and alloys treated at 825° or 950°C in a carburizing atmosphere show extensive carbide precipitation. This may be succeeded by the FeCr phase or by a carbide with a higher C content. Point analyses carried out with an electron microanalyser make it possible to study the depletion of Cr in the matrix after precipitation and to determine the chemical composition of carbides. In particular the Fe, Ni, and W content of the carbides, elements which replace Cr can be accurately determined.

Study on carbides in commercial special steels by electrolytic isolation. IX. On carbides in Mo and Co high speed steels T. Sato, T. Nishizawa, and K. Murai (*Tetsu to Hagane*, 1959, **45**, Dec., 1346–1351) Mo steels (0–9–4–2 and 6–5–4–2) showed M_6C, $M_{23}C_6$, and MC present. The density of carbides was less than in W steels, and austenitizing treatment produced more ready dissolution. 18–4–1–20 Co steel contained only M_6C. The addition of C enlarged the solubility limits of W, Cr, V, and other carbide-forming elements in austenite, and so promoted dissolution of M_6C during austenitizing (11 refs).—K. E. J.

Exaggerated expansion of grain and intergranular segregations in iron P. Coulomb (*Mét. Corros.-Ind.*, 1960, **35**, Jan., 1–23) A review, covering: the exaggerated expansion of soft iron; the role of hydrogen and effects of various factors; evolution of textures of soft iron and course of annealing under hydrogen and a comparison with pure iron annealed under H_2.

A comprehensive examination of samples of iron containing aluminous inclusions G. R. Booker, J. Norbury, and A. R. Westrope (*JISI*, 1960, **196**, Nov., 294–300) [This issue].

The solidification of hypoeutectic grey cast iron W. Oldfield (*BCIRA J. Res. Dev.*, 1960, **8**, March, 177–192) The eutectic graphite structure of grey cast iron is determined by the manner in which solidification takes place. Variables which influence cooling such as degree of nucleation of the eutectic and methods of controlling them are described. Experiments are reported which demonstrate that S and H reduce the radial growth of eutectic cells. The conditions of eutectic solidification which lead to the occurrence of the white iron eutectic are also discussed and reference is made to some properties which are affected by variation in the number of graphite eutectic cells.

The recrystallization pattern of solid metal solutions L. P. Kurilekh (*Metalloved. Term. Obra. Met.*, 1959, (9), 30–38) The main factor affecting recrystallization temp. of solid solutions is the ratio of the crystal parameters of the solvent and solute components. The dissolved elements with parameters larger than those of the solvent increase recrystallization temp. and vice versa.

Investigations on the recrystallization of an austenitic chromium–nickel steel with special reference to the duration of annealing H. Borchers, K. Bungardt, and D. Pusch (*Arch. Eisenhüt.*, 1960, **31**, April, 237–242) The structure, hardness, and magnetic saturation were examined of an austenitic 18 Cr 12 Ni steel with 0–70% cold working, after heating for 24 h at temp. up to 500°C. The structure and hardness were also studied after annealing at 500–1400°C for 1–2 h. A slight recovery was found at 500°C with 24 h heating. A fine-grain structure can be obtained above the critical range by prolonged annealing at lower temp. as well as by rapid annealing at higher temp. (17 refs).

The growth of the austenitic grain in medium carbon steels on heating at high temperatures Z. Volf and M. Foltýn (*Hutn. Listy*, 1960, **15**, (2), 127–129) Grain growth was studied in samples of a 0·35%C steel in the range 1200–1350°C. Evidence of burning first appears at 1250°C. The higher the temp. of annealing, above 1250°C, the sooner is evidence of burning obtained. Segregation at grain boundaries was investigated.—P. F.

Influence of temperature on the crystalline behaviour of an 18/8 austenitic steel subjected to alternating torsion fatigue stresses J. de Fouquet (*Rev. Mét. Mém. Sci.*, 1959, **56**, Sept., 357–370) Tests on rolled specimens from room temp. to 800°C showed the effects of temp. in the crystalline behaviour of the steel during the fatigue test. Appearance and formation of slip bands up to 650°C varied with temp., improved life being observed between 300 and 600° at constant torsion amplitude. Fissures and fracture were mainly intercrystalline up to 600°C; progressive polygonization was observed above 650°C, and the influence of this on fracture mechanism is discussed.

Eutectic cell count—an index of metal quality (*BCIRA J. Res. Dev.*, 1960, **8**, March, 221–231) The nature of eutectic cells is described and methods are given for revealing the cell patterns on an etched surface. A simple projection microscope is illustrated which facilitates comparison of numbers of cells. Three methods of comparison of eutectic cell numbers in iron castings of similar type have been investigated and assessed. Area and line counting are most suitable for research work but for routine control in foundry conditions the comparator method is quicker and provided the cell pattern is well-defined is very satisfactory.

Twinning in steels according to the state of tension, temperature and rate of stressing A. Kochendörfer (*Rev. Mét. Mém. Sci.*, 1959, **56**, Sept., 308–392) Experiments are described which indicate that three types of twinned structure are formed, and it is shown that there is no causal relationship between any of these forms and brittle fracture.

Qualities and structures in steels and metals. Influence of the geometrical factor and its determination of quality and quantity G. Arregui (*Met. y Electr.*, 1960, **24**, May, 140–142) A survey is given of physical concepts applied to structure and crystal structures; network systems, their cohesion and internal energy and their homogeneity and pattern of grain.—S. H.-S.

Transformation during heating N. N. Lipchin (*Metalloved. Term. Obra. Met.*, 1959, (11), 19–23) Investigations by various methods have shown that the much higher temp. for the grain refinement and the disappearance of texture during repeated rapid heating of previously quenched steel is related to the recrystallization of the cold-hardened austenite and to the usual recrystallization process determined by the alloying of the α-phase and by the rate of heating.

MISCELLANEOUS

Effect of alkaline earth metals on the magnetic permeability of the ferrous silicates Z. F. Gulyanskaya, V. P. Schastlivyi, and D. M. Chizhikov (*Izvest. AN Metallurg. i Topl.*, 1959, (5), 45–48) The magnetic permeability of alloys of the systems SiO_2–FeO–(Fe_2O_3) and of SiO_2–FeO–CaO (MgO, BaO) with a constant content of SiO_2 of between 5 and 48%, of FeO between 27 and 52% of CaO up to 30%, BaO up to 30% is conditioned principally by the concentration of ferric oxide. All components investigated are paramagnetic but the degree of paramagnetism depends on the temp. and the concentration of the added oxides and this is confirmed by the fact that if FeO or SiO_2 are replaced by CaO, MgO, or BaO in the FeO–SiO_2 alloys, with a constant content of ferrous oxide or silica, magnetic permeability decreases.

Observations on foundry silicosis H. J. Schmid (*Z. für Unfallmedizin v. Berufskrankheiten*, 1958, Sept., 221–231) Various aspects are described into research carried out, particularly at Schaffhausen of various lung affections caused by dust in the foundry industry, and a detailed study is made of the incidence of tuberculosis of the lungs among foundry workers. It is concluded that the quartz damage in the 'foundry lung' favours the development of tuberculosis, even in its mild forms. The possible causal relationship of bronchitis with silicosis is also discussed.

The silicosis-producing function of acid and silico-aluminous refractory materials in the steel industry E. Occella and G. Maddalon (*Met. Ital.*, 1960, **52**, April, 164–173) The results of petrographic and X-ray spectrographic examinations shed light on the evolution of the various forms of true crystalline silica and its distribution at varying distances from the molten baths. The composition of the various grain sizes obtained from samples is also studied. The investigation aims at establishing the basis for defining the silicosis producing action of refractories used in steel furnaces, particularly OH furnaces.

Defects in the crystal and magnetic structures of ferrous oxide W. L. Roth (*Acta Cryst.*, 1960, **13**, Feb. 10, 140–149).

An experimental study of labour hygiene during converter steel making. III. Water metabolism and blood constituents in moulders Y. Nambu, H. Muramoto, T. Kasai, Y. Norimatsu, R. Fujioka, M. Kiyonaga, M. Suzuki, K. Ono, M. Nagatomo, and K. Takayanagi (*J. Lab. Hyg.*, 1960, **9** Feb., 19–30). **IV. Urine constituents and labour fatigue in moulders** (30–38).

The third law entropy and structure of iron pentacarbonyl A. J. Leadbetter and J. E. Spice (*Can. J. Chem.*, 1959, **37**, Nov., 1923–1929) Heat capacity of solid and liquid $Fe(CO)_5$ has been measured from 20–200°K; heat of fusion was found to be 3161 ± 3 cal/mole. Heat of vaporization at 25°C was estimated to be 9·1 ± 0·1 kcal/mole. Entropy as an ideal gas at 1 atm. and 25°C is calculated at 106·4 ± 0·8 cal/mole/°, and it is deduced that the molecule is a trigonal bipyramid (16 refs).

Study on the production of metallic magnesium by the reduction method. II. On the reduction of MgO–CaO with Fe–Si M. Ikeda (*Nippon Kinzoku*, 1959, **23**, March, 152–156) The yield of Mg increases with temp., the activation energy is 55 kcal/mol. The yield is a max. at MgO/Si = 1. Adding CaO increases the yield, and Al_2O_3 or Fe_2O_3 decreases it. $2CaOSiO_2$ and $3CaO2SiO_2$ were found in the residue. There is little difference between reduction by Fe–Si and Ca–Si, except the lower cost of the former.

The effects of high dose rates of ionizing radiations on solutions of iron and cerium salts J. Rotblat and H. C. Sutton (*Proc. Roy. Soc.*, 1960, **255**, May 10, 490–508).

Magnetic moment of ^{57}Fe G. W. Ludwig and H. H. Woodbury (*Phys. Rev.*, 1960, **117**, March, 1286–1287).

Principal aims of the present activities of C.E.C.A. in the field of operational safety in the iron and steel industry A. Claass and G. Will (*PACT*, 1959, **13**, Dec., 446–453) The work being done by the Communauté Européenne du charbon et de l'Acier is described, under the headings of works accident prevention, health and hygiene, and rehabilitation measures.

BOOK NOTICES

ANGUS, H. T. '*Physical and Engineering Properties of Cast Iron*'. A data book for Engineers and Designers. 9½ × 7 in., pp.528. Illustrated. 1960, Alvechurch: The British Cast Iron Research Association. (Price, Members £2 12*s*. 6*d*; Non-members £3 13*s*.6*d*.)

Book reviews commonly make reference to the fact that 'the author is an authority on his subject': this review is no exception. No man in Britain today, other than Dr H. T. Angus, could have assembled together under one cover such a mass of reliable data on cast iron. This book is the masterpiece of one devoted to his subject, backed by 40 years professional experience and holding high personal standards of accuracy and lucid expression. Furthermore, the author has enjoyed the facilities and backing of the British Cast Iron Research Association which today stands in stature second to none in the world as a source of reliable information on cast iron.

The book has nine parts, each with a carefully worded caption and a very useful appendix of summarized data. Where references to the literature are given, the reader may be assured that these are carefully screened and are a concise guide to the particular subject. This is no mere indiscriminate review of the work of others; each fact given and statement made has survived the test of time in the author's working notebook and has passed the trial of practical utility. Engineers will like the book, for it gives them the answers in a clear, direct manner, not veiled in metallurgical jargon. Students will buy it and keep it as a book of reference not to be found in a few years' time on the second-hand stall. Those responsible for iron foundries will find it is an indispensable comprehensive account of iron as a modern constructional material.

—R. V. RILEY.

DARWIN, G. E. and BUDDERY, J. H. '*Beryllium*' (Metallurgy of the Rarer Metals series—7). 8½ × 5½ in., pp.ix + 392. Illustrated. 1960, London: Butterworths Scientific Publications. (Price £3 10*s*.)

Metallurgists who have mentally dismissed beryllium as a minor alloying element for certain copper alloys will be astounded at the wealth of information which the authors have presented on the technology of this element. Isolated first in 1828, the element for many years had the alternative name of glucinum (Gl.) which has now been completely superseded. The main stimuli to development are the extremely low thermal neutron absorption cross-section which makes the element extremely useful for nuclear purposes, and the combination of high strength and very low density (1·8 g/cc) which makes it potentially desirable for aircraft and missile applications. The authors cover the whole technology of metal production and fabrication, and state that reduction of the fluoride by magnesium or low temperature electrolysis of a beryllium chloride–sodium chloride mixture are the most attractive processes for commercial production of the metal. This is best further purified by vacuum melting, comminuted, and then processed by powder metallurgy using hot pressing and extrusion techniques. The physical, mechanical, or nuclear properties are covered in detail, and in contrast to the favourable characteristics mentioned above, attention is also drawn to the marked anisotropy, and the poor ductility impact and notched strength. The authors comment on the lack of information on properties in tube form, an omission which will no doubt be made good because of the interest in beryllium as a canning material for the British Advanced Gas-Cooled Reactor. Sections have also been devoted to the preparation and properties of beryllia, use of the element as a minor alloying addition, and alloys and compounds based on the metal. This authoritative reference volume must be the most complete technical survey available on beryllium, and is indispensable to all interested in this 'Rarer Metal'.—H. C. CHILD.

LISTER, R. '*Decorative Cast Ironwork in Great Britain*'. 8½ × 5½ in., pp.xii + 258. Illustrated. 1960, London: G. Bell and Sons Ltd. (Price £1 15*s*. 0*d*.)

The author, who wrote *Decorative Wrought Ironwork in Great Britain*, introduces his subject with a brief historical survey about the advent of cast iron in which he stresses the differences from wrought metal. He contrasts the production and application of each, and reinforces the impression that any aesthetic scrutiny of cast ironwork must take into account the intervention of men skilled in the use of many non-ferrous materials. The varied techniques, media, and tools used by contemporary moulders, patternmakers, and founders are described in detail, and the reader may reasonably assume that with minor exceptions the basic principles involved have not changed much during the past 400 years.

One chapter, devoted to an assessment of the early gunfounders and their cannon, indicates the main impulses behind the emergence of the large, well organized foundries of the eighteenth century. Innumerable domestic cast iron objects are described, ranging from Elizabethan hearth fittings to modern utensils. Grave slabs, grates, stoves, furniture, and garden gear represent only a small portion of the topics covered. The origins of the styles and decorative motifs employed are discussed, while attention is directed to the influence or participation of well-known designers, often in quite humble fields. A major and most important part of the book deals with the structural and architectural uses of cast iron. It surveys comparatively simple applications in the form of gates, railings, and minor public works; the monumental achievements of the great engineers, all the wonders of Victoriana and present-day trends. Much interesting material is included in a chapter on surveyors' ironwork and allied subjects. In concluding with an account of the status, organization, and environment of the foundry worker past and present, the author of this comprehensive book succeeds in portraying the traditional background to a progressive modern industry. A useful glossary of ironfounding terms and an extensive bibliography are provided, as well as excellent illustrations.—J. W. ANSTEE.

NEW PUBLICATIONS

These titles are also available on index cards in advance of publication in the Journal, *each title being classified under the Universal Decimal system (UDC). Details and subscription rates can be obtained from the Secretary, The Iron and Steel Institute.*

BRUNHUBER, E. '*Legierungs Handbuch der Nichteisen Metalle*'. 2. Aufl. 8 × 6 in., pp.312. Illustrated. Berlin, 1960: Fachverlag Scheile & Schon Gmbh. (Price DM.38.–)

COMMISSARIAT A L'ENERGIE ATOMIQUE (CEA). Institut National des Sciences et Techniques Nucléaires—Département de Métallurgie. Centre d'Etudes Nucléaires de Saclay (CEN). '*3e Colloque de Métallurgie Corrosion (Séche et Aqueuse). Organisé à Saclay les 29–30 juin et 1er juillet 1959 par M. Salesse sous la présidence de Professeur Chaudron*'. 10¾ × 8¼ in., pp.240. Illustrated. Gif-sur-Yvette (S–et–O); Amsterdam, 1960: Centre d'Etudes Nucléaires de Saclay; North Holland Publishing Co.

WESTBROOK, J. H. (Editor.) '*Mechanical Properties of Intermetallic Compounds*'. A symposium held during the 115th meeting of the Electrochemical Society at Philadelphia, 3–7 May 1959. 9 × 6 in., pp.ix + 435. Illustrated. New York, London, 1960: John Wiley & Sons Inc., Chapman & Hall Ltd. (Price £3 16*s*.)

OVERSEAS GEOLOGICAL SURVEYS. Mineral Resources Division. '*Statistical Summary of the Mineral Industry*'. World Production, Exports, and Imports 1953–1958. 9½ × 6 in., pp.iv + 389. London, 1960: Her Majesty's Stationery Office. (Price £1 7*s*. 6*d*.)

SMALES, A. A. and WAGER, L. R. (Editors.) '*Methods in Geochemistry*'. 9×6 in., pp.vii+464. Illustrated. New York, London. 1960: Interscience Publishers Ltd. (Price £4 14*s*.)

ANGUS, H. T. '*Physical and Engineering Properties of Cast Iron*'. A Data Book for Engineers and Designers. 9½×7 in., pp.528. Illustrated. Alvechurch, Birmingham, 1960: The British Cast Iron Research Association. (Price, Members £2 12*s*. 6*d*.; Non-Members £3 13*s*. 6*d*.)

ROBERTS, C. S. '*Magnesium and its Alloys*' (Wiley series on the Science and Technology of Materials). 9×6 in., pp.xi+230. Illustrated. New York, London, 1960: John Wiley & Sons Inc., Chapman & Hall Ltd. (Price £3 12*s*.)

LISTER, R. '*Decorative Cast Ironwork in Great Britain*'. 8½×5½ in., pp.xii+258. Illustrated. London, 1960: G. Bell & Sons Ltd. (Price £1 15*s*.)

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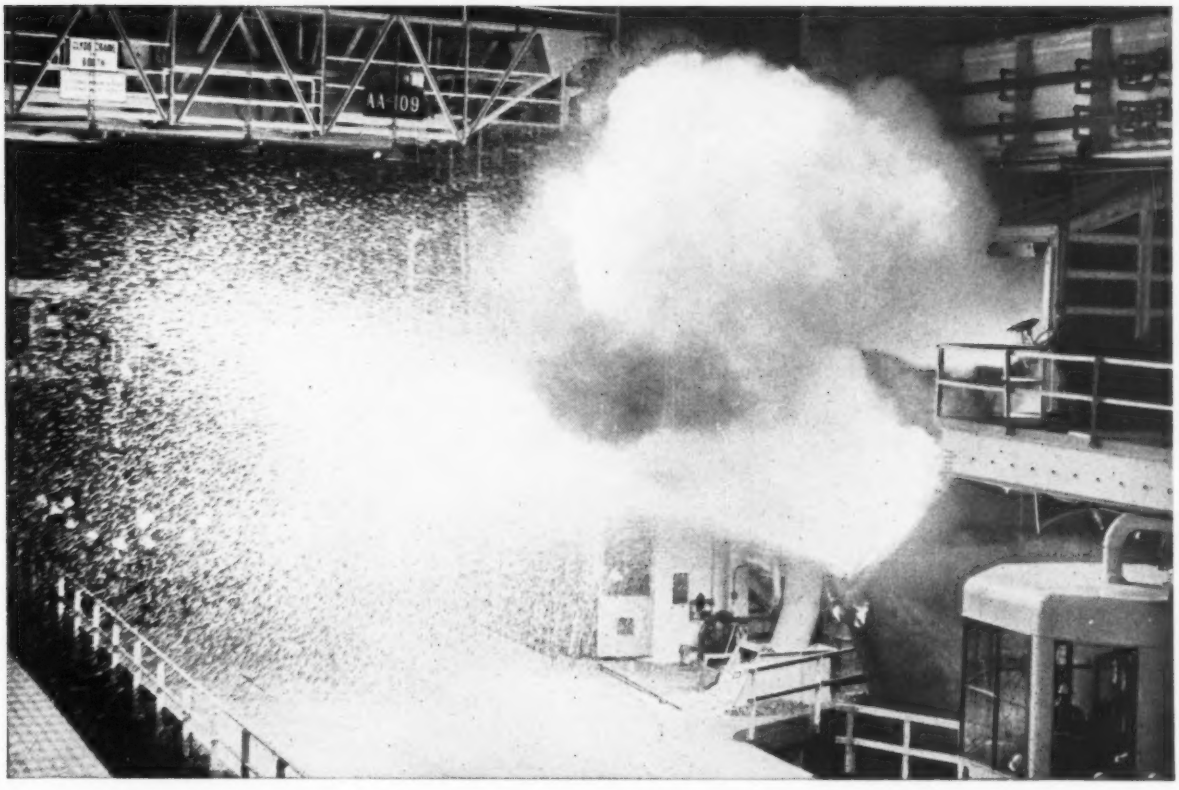

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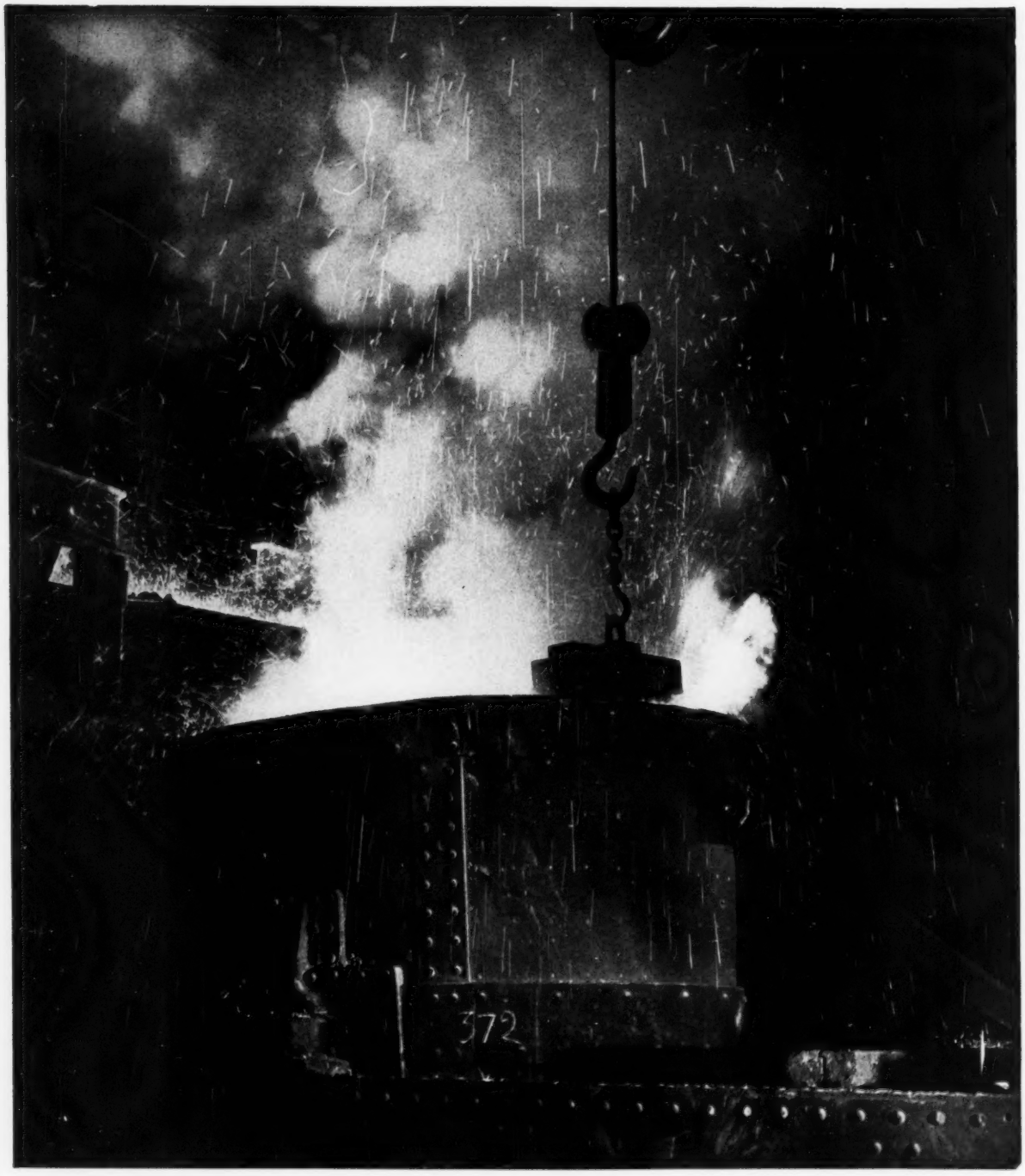

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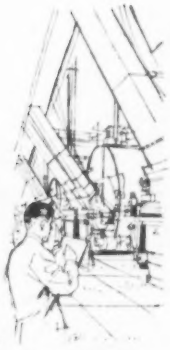

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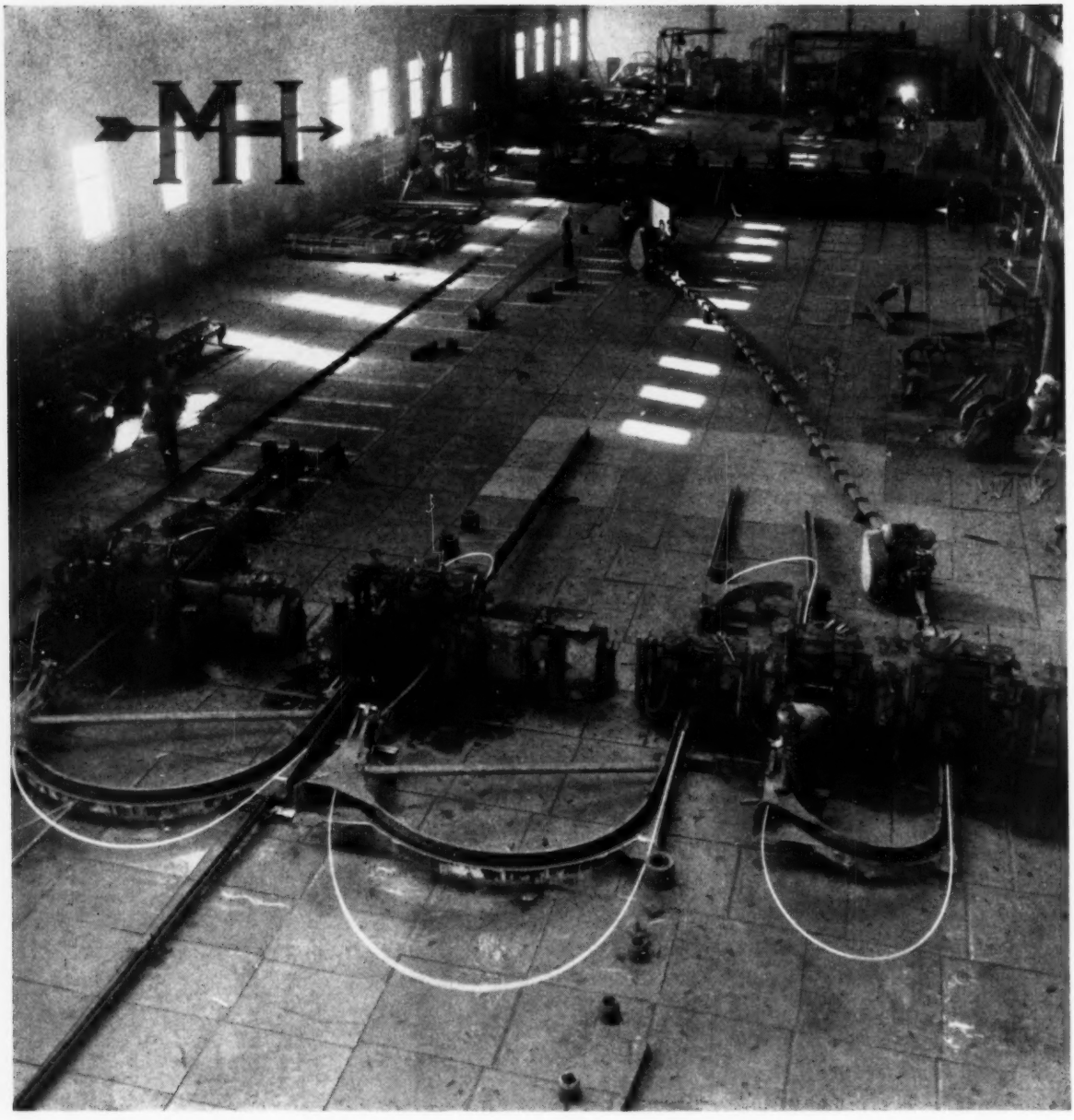

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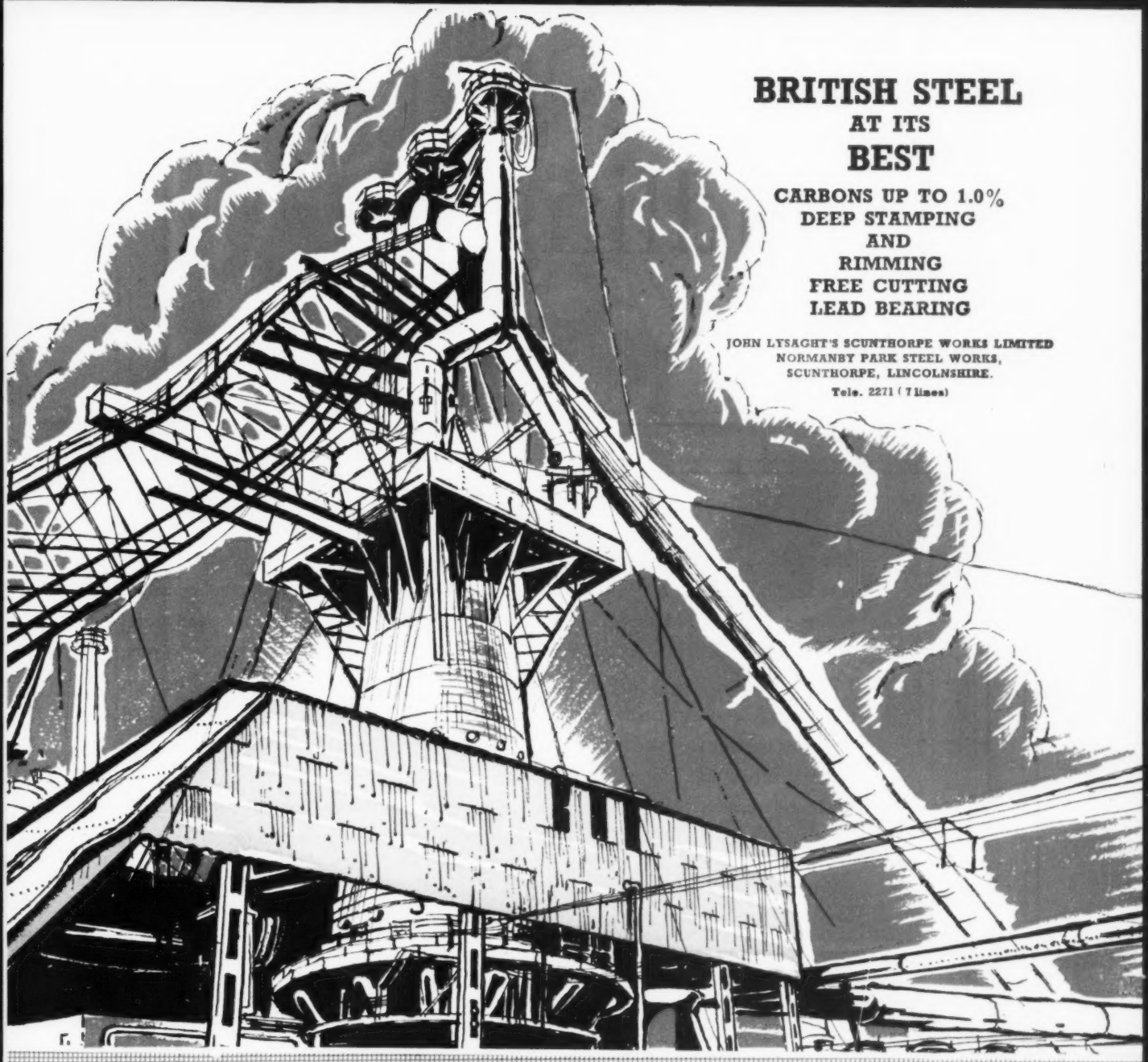

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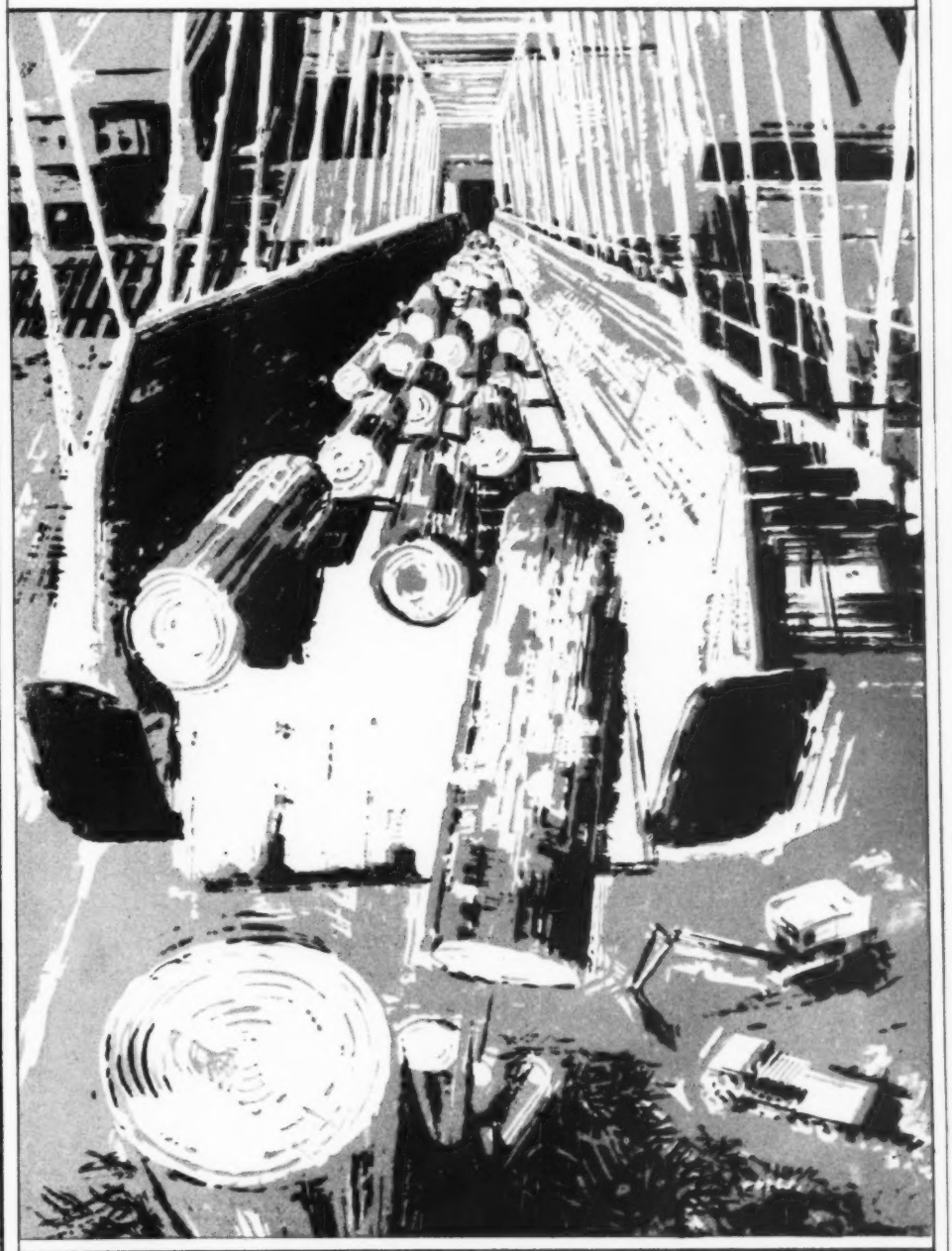

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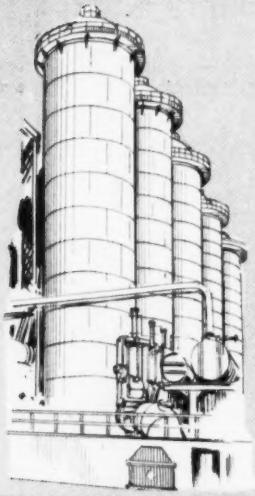

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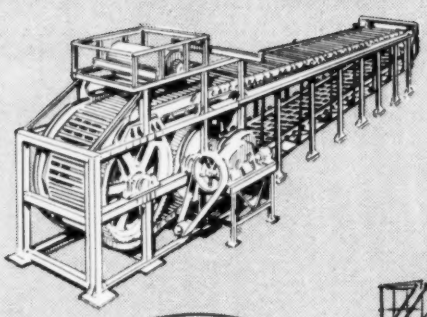

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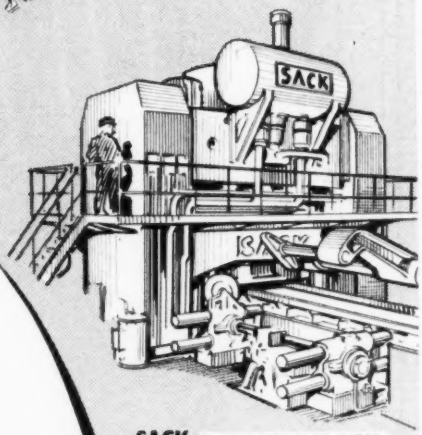

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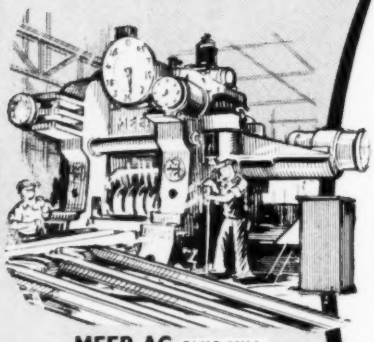

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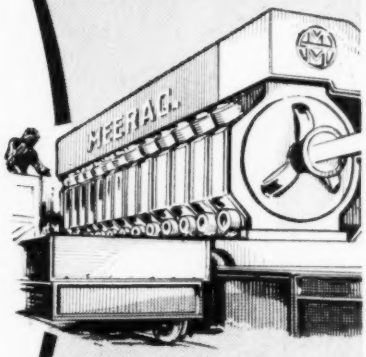

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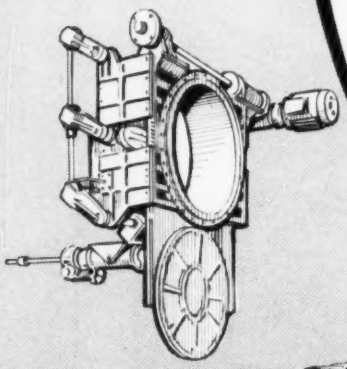

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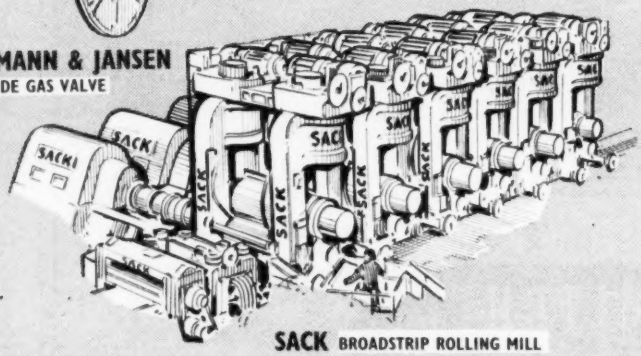

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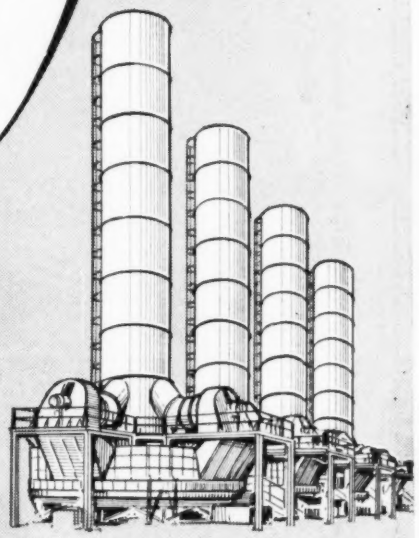

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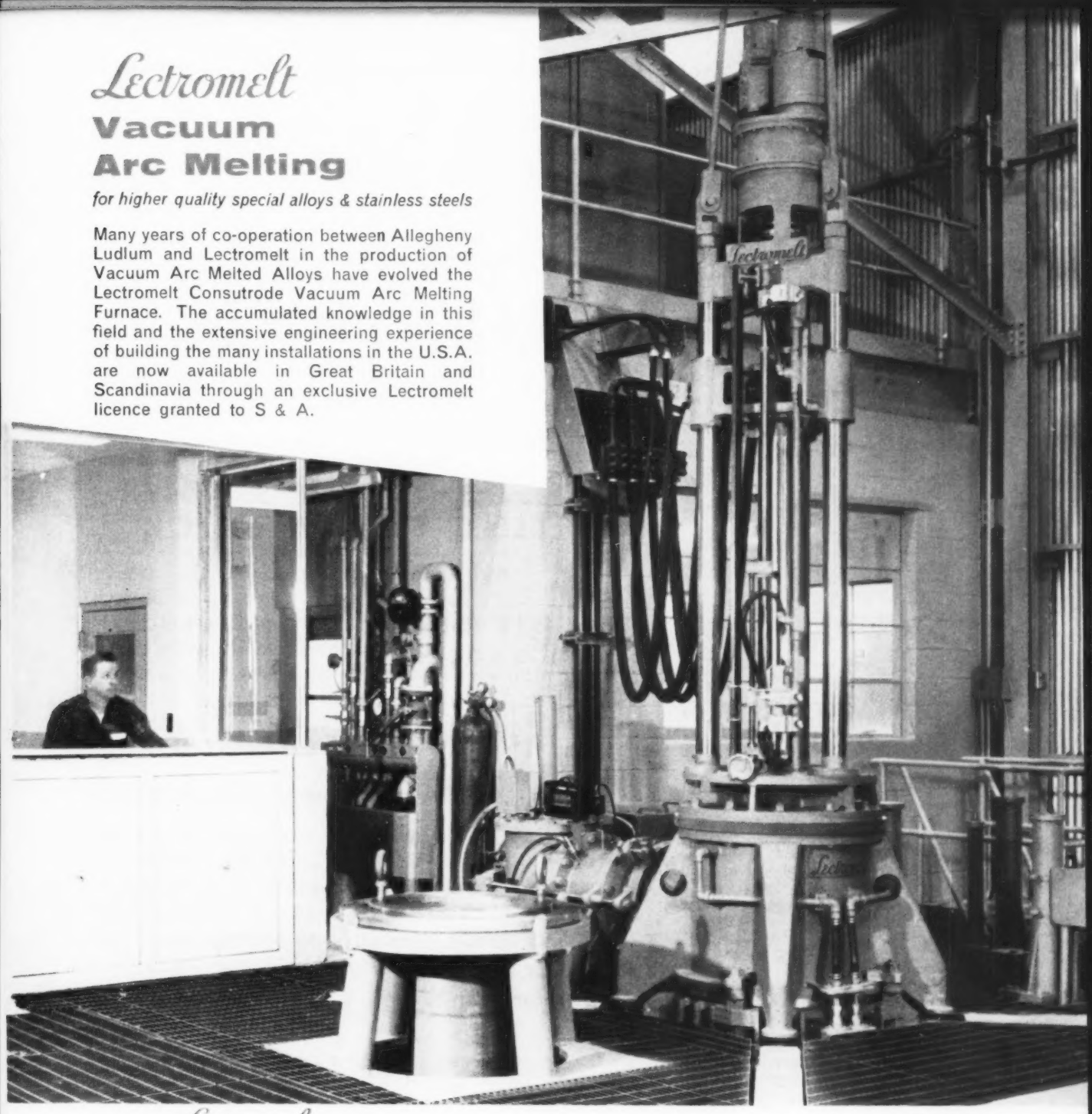

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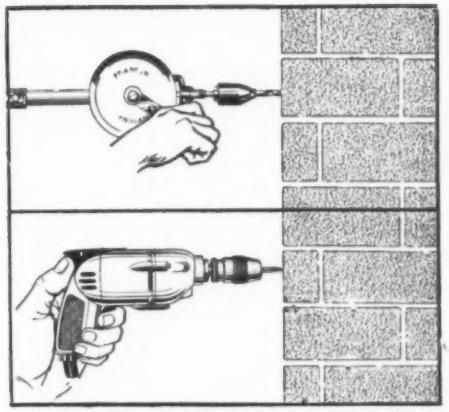

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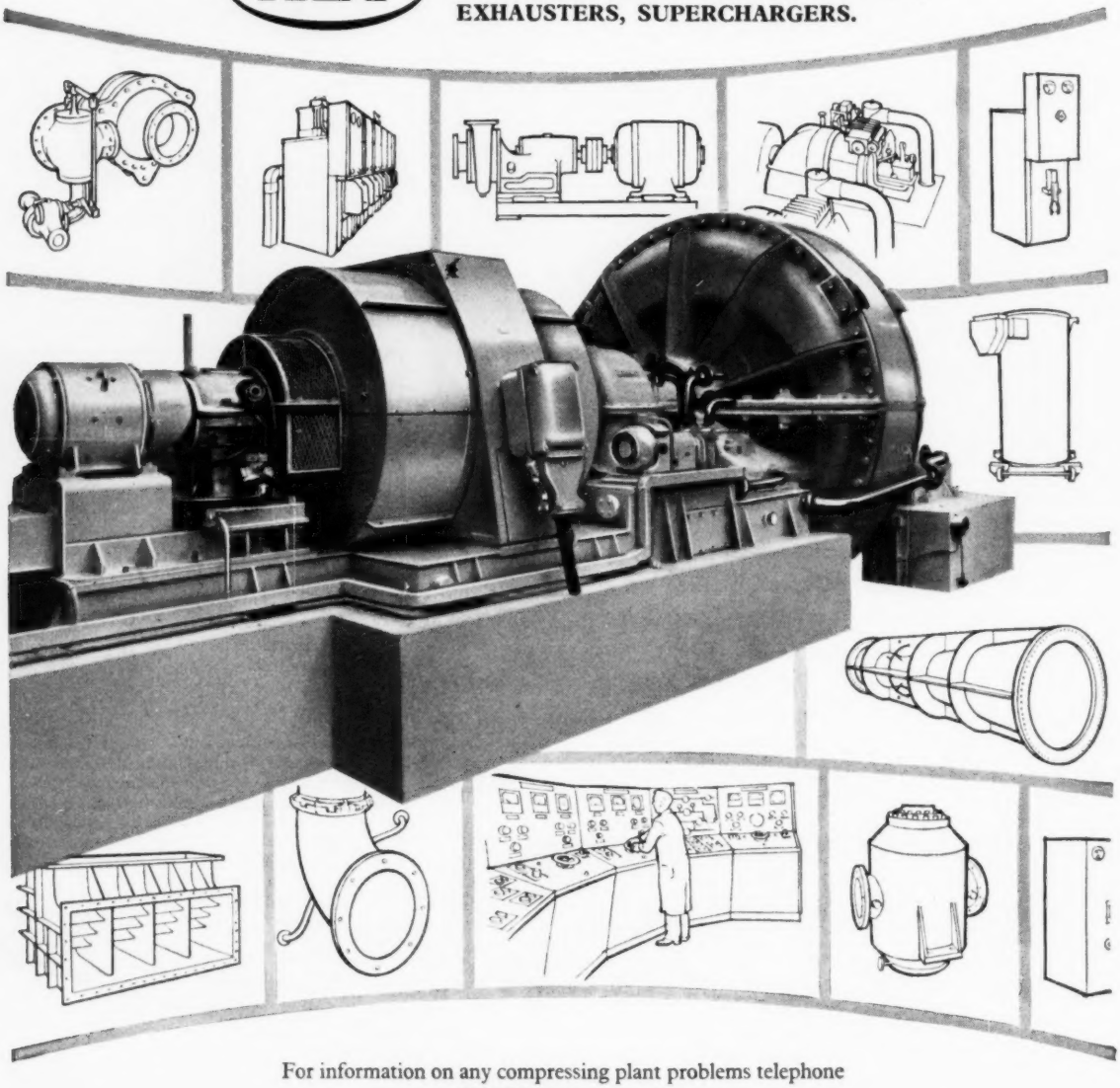

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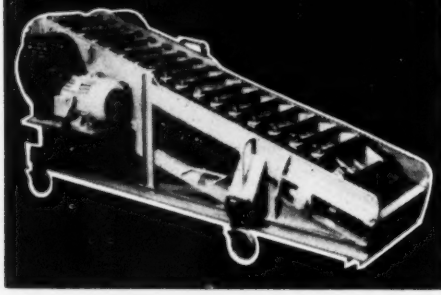

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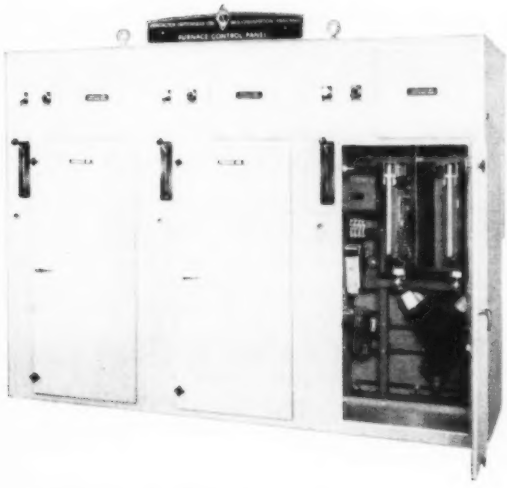

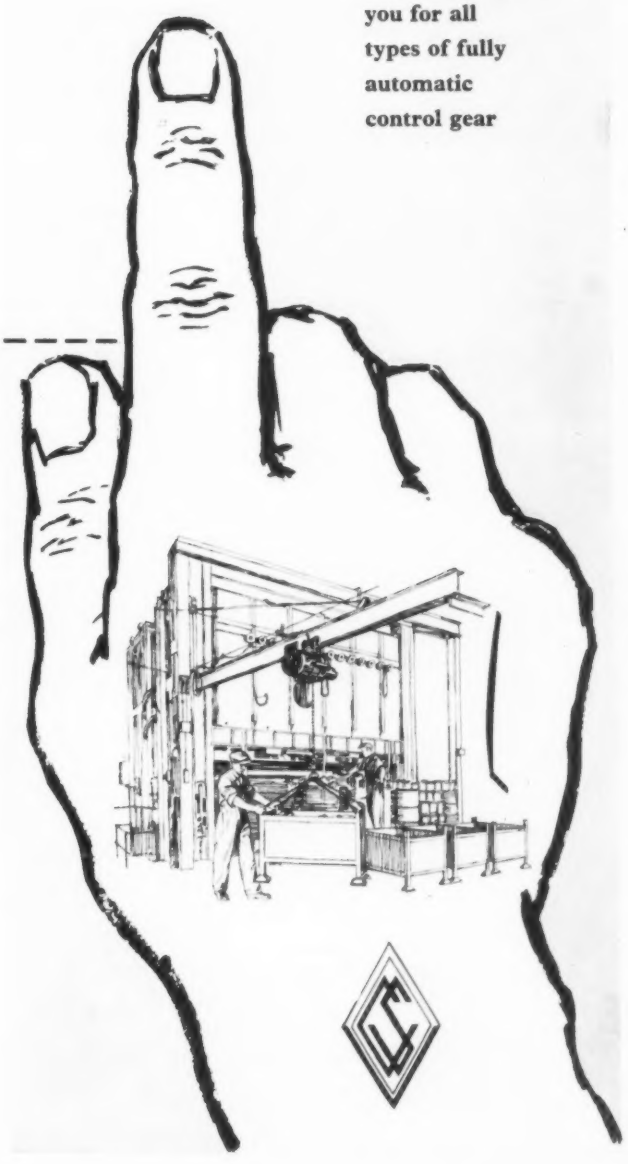

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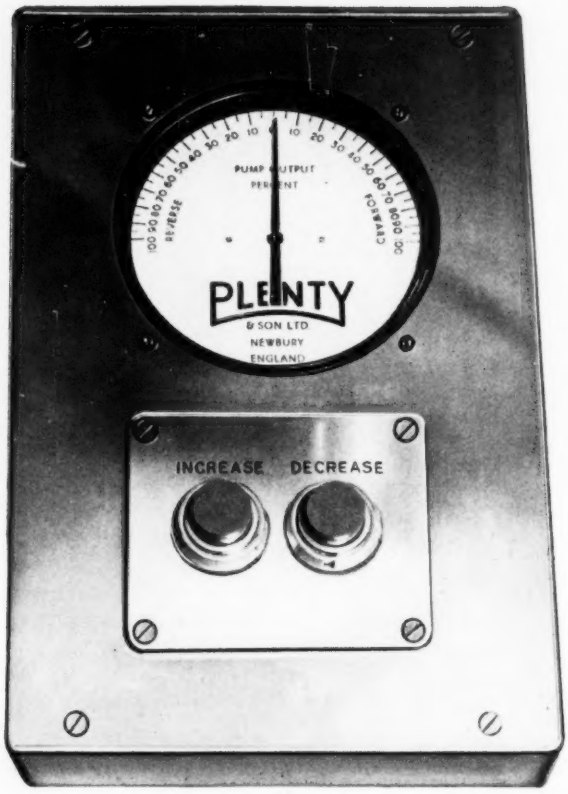

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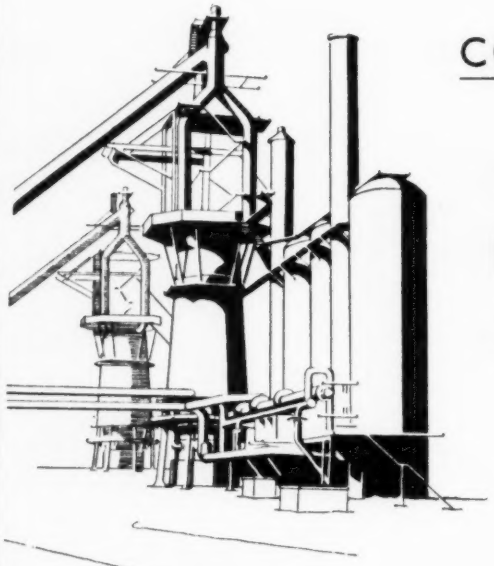

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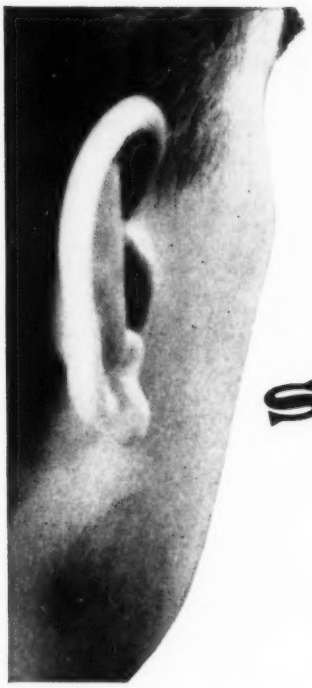

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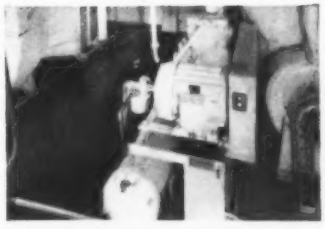

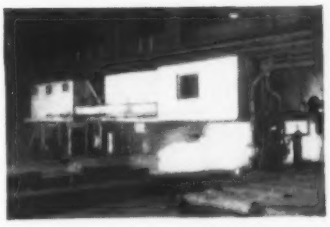

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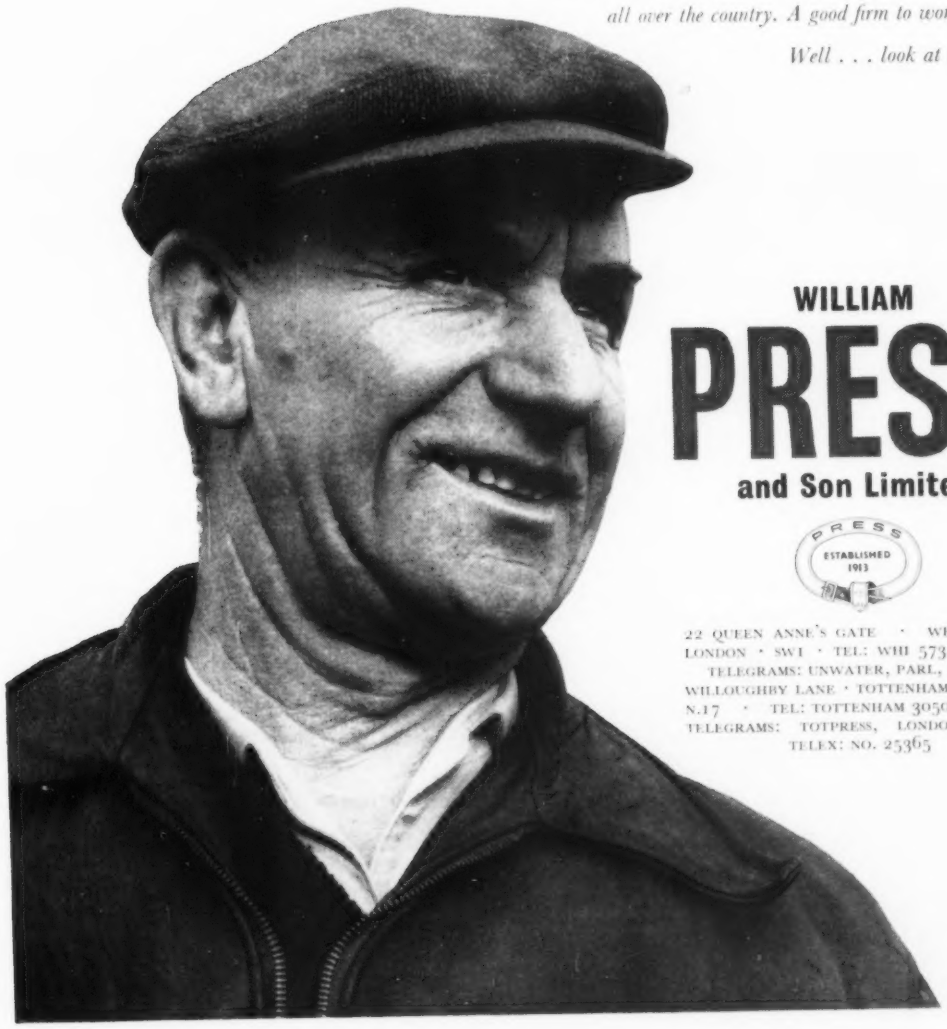

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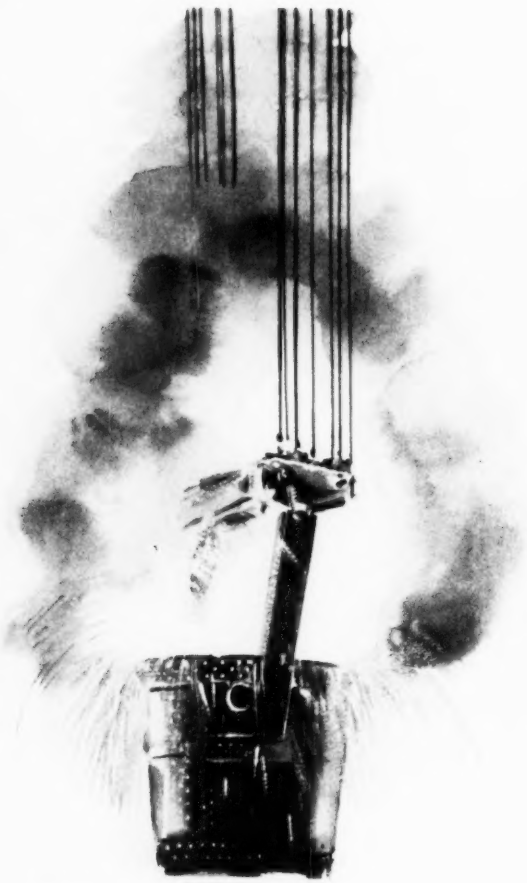

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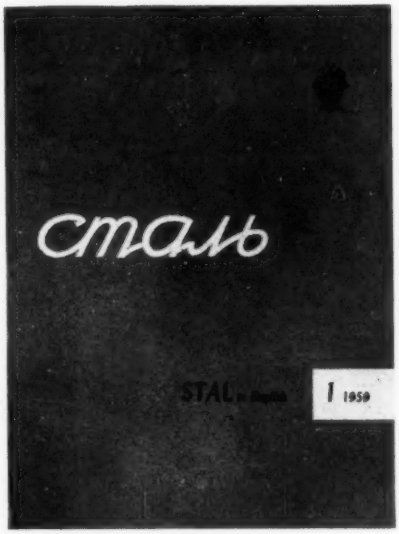

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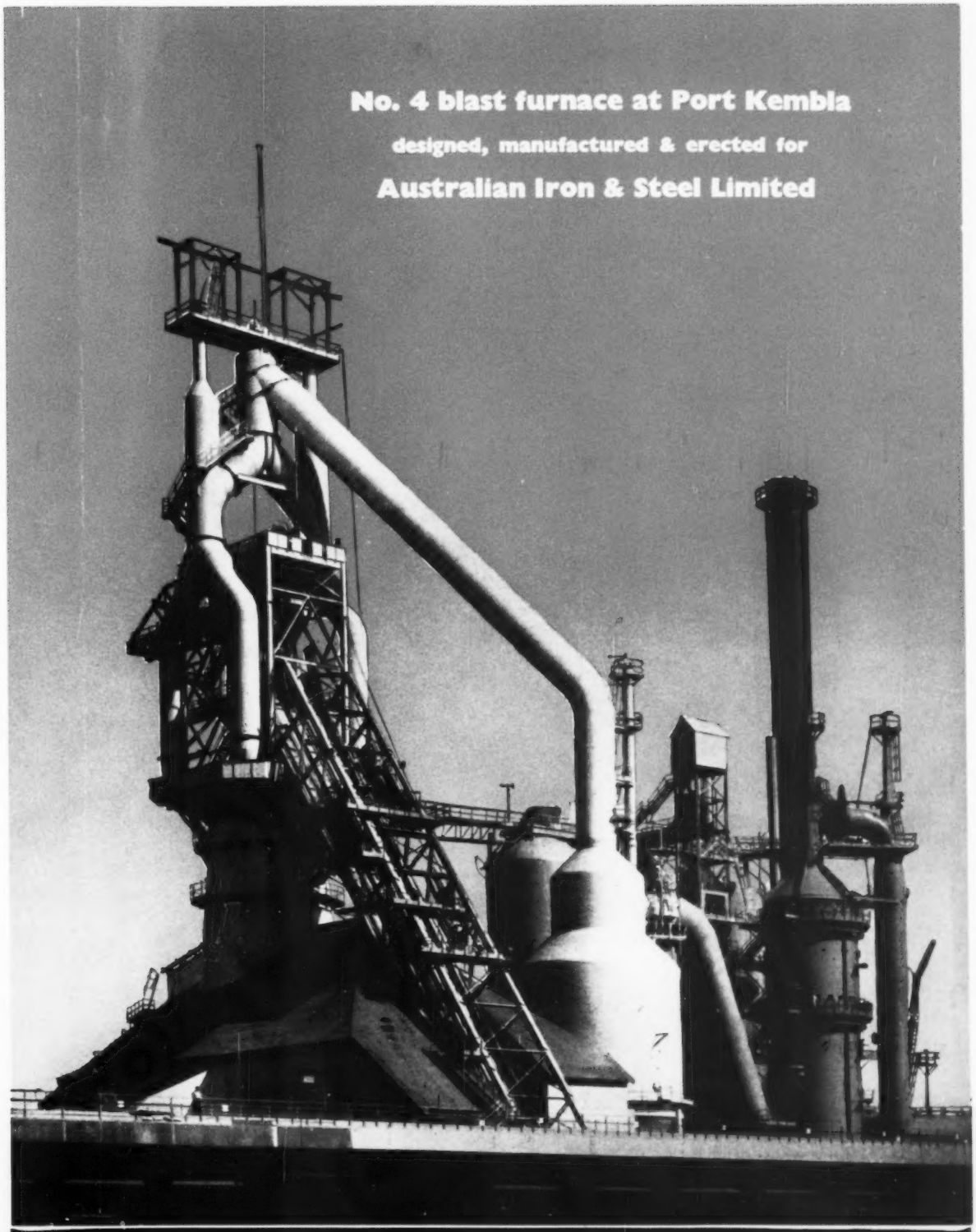

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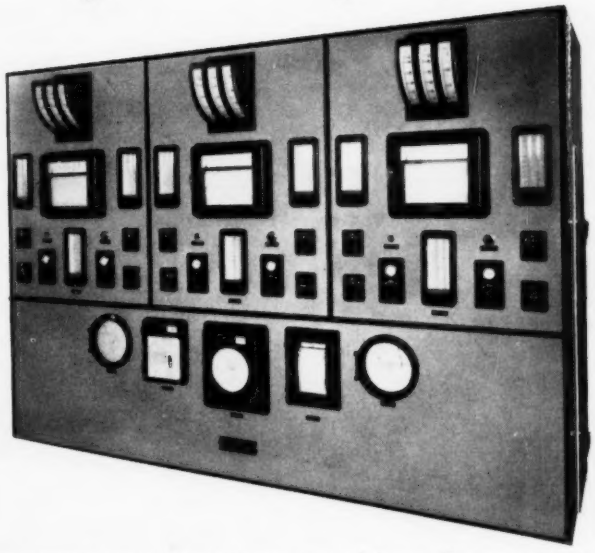

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